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SINGLE SCATTERING CODE AGAUSX: THEORY, APPLICATIONS, COMPARISONS, AND LISTING

JULY 1980

By

RICHARD C. SHIRKEY

US ARMY ATMOSPHERIC SCIENCES LABORATORY
White Sands missile range, New Mexico 88002

AUGUST MILLER
GEORGE H. GOEDECKE
YUGAL K. BEHL

DEPARTMENT OF PHYSICS
NEW MEXICO STATE UNIVERSITY
Las Cruces, New Mexico 88003

US Army Electronics Research and Development Command
ATMOSPHERIC SCIENCES LABORATORY
White Sands Missile Range, NM 88002

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Since the overall running time of Mie codes may be greatly reduced by reducing the number of particle sizes treated, it is desirable to have a code in which one may specify an acceptable level of accuracy and which then uses only as many particle radius values as are needed to satisfy that requirement; AGAUSX is such a code. The user of AGAUSX can specify a "convergence" level which represents the minimum fractional accuracy that is acceptable for certain results of a run. Other capabilities offered by AGAUSX include provisions for (1) producing phase functions, scattering fractions or an analytic phase

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function; (2) cycling over a range of wavelengths; (3) treating changes in hygroscopic particle sizes; (4) treating milticomponent aerosols differing in specific gravity and/or optical properties; (5) options whereby users can either input particle number density or mass density and mass concentration; (6) various size distribution models; and (7) automatic look up and/or interpolation of optical constants for liquid water. A comparison of AGAUSX with other Mie codes is also presented.

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INTRODUCTION

The increasing need for information concerning the effects of aerosols upon electro-magnetic radiation passing through media containing these aerosols requires continual improvement of existing processes. As our understanding of these processes improves, the need for sophisticated numerical codes capable of accurately representing such theory continually increases. It is to this end that computer program AGAUSX (and its predecessors) has been constructed.

PROGRAM AGAUSX

Experience acquired over a period of several years with various versions of the single scattering codes PGAUSS and AGAUS has revealed that users of such codes often tend to be over conservative in their choice of the number of radii at which Mie calculations are performed. Many single scattering codes require that the user specify some input parameter such as the total number of radii to be used. Unless a user has had a great deal of experience with choosing such parameters for various types of size distributions, there is a tendency to use many more radii than may be needed to obtain results at acceptable levels of accuracy. Since the overall running time of Mie codes may be greatly reduced by reducing the number of particle sizes treated, it is desirable to have a code in which one specifies an acceptable level of accuracy and which then uses only as many particle radius values as are needed to satisfy that requirement. Rather than specifying the number of radii, the user of AGAUSX must specify a "convergence" level DELTA. The quantity DELTA represents the minimum fractional accuracy that is acceptable for certain results of a run. In operation, AGAUSX then runs through the Mie calculations and integrations over size using only a few particle radii and obtains first estimates of extinction coefficients, etc. The size intervals are then reduced to one-half their former value and new estimates are calculated. If the new and old estimates agree to within (DELTA x 100) percent, then AGAUSX ceases to treat additional particle sizes and proceeds to its final calculations. If the new estimate does not agree with the "old" one to within (DELTA x 100) percent, the size interval is again cut in half and the calculations and comparisons are repeated. The cycling occurs repetitively

until either the convergence criterion is satisfied or until some precoded maximum number of values (513 for AGAUSX) for particle radius have been used.

It is believed that AGAUSX will represent a substantial advancement in aerosol modeling because it contains a large variety of size distributions, the possibility of modeling mixtures of aerosols with different optical properties, treats changes in particle size with variable relative humidity, is compatible with ACT[+] and will probably provide substantially shorter computation times than most existing aerosol codes. In addition AGAUSX has the capability of producing an analytic phase function when quick results of intermediate accuracy are desired.

In summary, program AGAUSX is a versatile, single scattering, state of the art computer code capable of performing the following:

(1) Provisions for producing (a) phase functions, (b) Legendre coefficients or (c) scattering fractions compatible with ACT.

(2) Provisions for producing an analytic phase function represented by Legendre coefficients.

(3) Provision for automatic cycling over a range of wavelengths and averaging of results over such a range of wavelengths.

(4) Provision for treating changes in hygroscopic particle sizes which may occur with variations in relative humidity.

(5) Provision for treating multicomponent aerosols differing in specific gravity and/or optical properties.

(6) Availability of options whereby users can either define particle number densities or let them be calculated from mass density and mass concentration.

[+]Atmospheric Sciences Laboratory - Chemical Systems Laboratory - TRADOC Systems Analysis Agency, Battlefield/Smoke Obscuration Code.

(7) Availability of options whereby users can select various size distribution models, including:

(a) Log Normal

(b) Double Exponential

(c) Dermendjian's Model C

(d) Power Laws

(e) Khirgian - Mazin

(f) Modified Gamma whose control parameters may include liquid water content

(g) Four Bimodal Log-Normal

(h) Marshall - Palmer rain model

(i) User Supplied

(8) Inclusion of an internal subroutine to provide automatic look up and/or interpolation of optical constants for liquid water at wavelengths between 0.35μm and 200μm.

(9) Inclusion of built-in internal checks to warn users if certain computed quantities seem to be failing to converge and extended error messages associated with failures in the Mie routine.

Every effort has been made to insure that program AGAUSX is machine independent. To this end AGAUSX has been written in ASCII FORTAN, and is available in the form of BCD punched deck. Should the user have any questions, discover possible inaccuracies, or simply be desirous of a punched deck, please contact R. C. Shirkey, AUTOVON 258-4200 or (505) 678-4200.

MIE THEORY

Mie theory[1] predicts the scattering by and the absorption in an isolated, discrete, homogeneous, isotropic sphere of diameter D with a known complex refractive index n = m-ik relative to the surrounding medium and illuminated by monochromatic radiant energy with wavelength λ in the surrounding medium. The theory is given in detail in standard texts and need not be repeated here. Instead, only those elements of theory needed for an understanding of the numerical algorithms used in AGAUSX are included.

Scatterers attenuate beams of radiant energy by scattering some of the energy into directions other than the incident or forward direction and by absorbing some of the incident energy within the body of the particle. The combined effect of pure scattering by the particle and true absorption within the particle is termed extinction. The amount of extinction, scattering and absorption by a single particle is given in terms of corresponding equivalent blocking areas or cross sections, C_{ext}, C_{sca}, and C_{abs}, respectively. These cross sections depend only on the refractive index of the particle n = m-ik and the size parameter $\alpha = 2\pi r/\lambda$, where r is the particle radius, and λ is the wavelength.

The transmission, T, of a cloud of particles of geometric depth, d, and number density, N, is given by

$$T = e^{-\tau}, \qquad (1)$$

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[1]G. Mie, 1908, "Considerations on the Optics of Turbid Media, Especially Colloidal Metal Sols," Ann Phys, 25

with the optical depth, τ, given by

$$\tau = K_{ext} \cdot d, \tag{2}$$

where

$$K_{ext} = NC_{ext}. \tag{3}$$

The balance between loss by scattering and loss by absorption is frequently characterized by the albedo of single scattering ω_o, given by

$$\tilde{\omega}_o = \frac{C_{sca}}{C_{sca} + C_{abs}} = \frac{C_{sca}}{C_{ext}} . \tag{4}$$

A scatterer with $\tilde{\omega}_o = 1$ has no absorption and is termed a conservative scatterer. The albedo $\tilde{\omega}_o$ gives the probability that a photon encountering the scatterer will be scattered into some direction including the incident direction.

Although the extinction by a cloud of particles is correctly given by equations (1) and (2), two implicit assumptions may lead to improper use of the equations. The optical depth τ in equation (2) does not include losses caused by absorption in the medium surrounding the particles. This assumption obviously breaks down at wavelengths for which atmospheric gases absorb appreciably. The second assumption is that scattered photons never return to

the incident direction, i.e., that there is no multiple scattering. This effect becomes increasingly important as optical depths exceed $\tau = 0.1$ for broad band propagation.[2,3] For laser wavelengths the effect is increasingly important as τ goes beyond a value of 15.[2,3]

A final caution should be noted in regard to absorption within the particle. Although absorption within the particle is correctly determined by the wavelength-dependent imaginary part k of the refractive index n, the explicit mechanism which causes the absorption is usually not specified. Usually the absorption is joule heating and it is sometimes necessary to account for the isotropic black body radiation emitted by the scatterer when its temperature rises above that of its surroundings. There may also be circumstances when quantum transitions occur in the scatterer followed by emission at or near the same wavelengths. It is incumbent on the user of the numerical algorithms presented here to properly include these effects since they are not automatically accounted for in these algorithms.

All scattering properties of spheres are computed from m and k, and through the use of the induced electric and magnetic multipole moments of the sphere a_n and b_n, respectively. The moments are given by*

$$a_n = \frac{\Psi_n'(n\alpha)\Psi_n(\alpha) - n\,\Psi_n(n\alpha)\Psi_n'(\alpha)}{\Psi_n'(n\alpha)\xi_n(\alpha) - n\,\Psi_n(n\alpha)\xi_n'(\alpha)}, \qquad (5)$$

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[2]S. Hoijer, 1974, Atmospheric Attenuation of a Light Beam Due to Scattering and Absorption, Research Institute of National Defense, FOA-2-C-2659-E1-E2-E3-E4

[3]O. Steinvall, 1974, Computed MIE Scattering Properties for Laser Wavelengths in Various Atmospheric Media, Research Institute of National Defense, FOA-2-C-2662-E1-E3

*Note that n is used as a subscript, an integer index, and a complex index of refraction when it is not a subscript.

and

$$b_n = \frac{n\Psi_n'(n\alpha)\Psi_n(\alpha) - \Psi_n(n\alpha)\Psi_n'(\alpha)}{n\Psi_n'(n\alpha)\xi_n(\alpha) - \Psi_n(n\alpha)\xi_n'(\alpha)} \cdot \tag{6}$$

The prime denotes differentiation with respect to the argument. The $\Psi_n(z)$ and $\xi_n(z)$ functions are Ricatti-Bessel functions of the first and third kind, respectively, and are related to the spherical Bessel functions $j_n(z)$ and $n_n(z)$ by

$$\Psi_n(z) = zj_n(z), \tag{7}$$

and

$$\xi_n(z) = zj_n(z) - izn_n(z) = \Psi_n(z) + i\chi_n(z), \tag{8}$$

where

$$j_n(z) = \left(\frac{\pi}{2z}\right)^{1/2} J_{n+1/2}(z), \tag{9}$$

and

$$n_n(z) = \left(\frac{\pi}{2z}\right)^{1/2} N_{n+1/2}(z). \tag{10}$$

The function $J_{n+1/2}(z)$ is the half integral order Bessel function; the function $N_{n+1/2}(z)$ is the half integral order Neuman function.

The extinction cross section is computed from

$$C_{ext} = \frac{\lambda^2}{2\pi} \sum_{n=1}^{\infty} (2n+1)\ \mathrm{Re}\ (a_n+b_n), \tag{11}$$

and the scattering cross section from

$$C_{sca} = \frac{\lambda^2}{2\pi} \sum_{n=1}^{\infty} (2n+1)\ [|a_n|^2+|b_n|^2]. \tag{12}$$

The various cross sections are the basic quantities used in scattering problems, but they are not the quantities usually computed directly from Mie algorithms. Instead, it is more convenient to compute dimensionless efficiency factors Q_{ext} and Q_{sca}, which depend on n, k, and α, and which are multiplied by the geometrical sphere cross section to obtain the true cross section $C_i = \pi r^2 Q_i$. Thus,

$$Q_{ext} = \frac{2}{\alpha^2} \sum_{n=1}^{\infty} (2n+1) \text{ Re } (a_n+b_n), \tag{13}$$

and

$$Q_{sca} = \frac{2}{\alpha^2} \sum_{n=1}^{\infty} (2n+1) \left[|a_n|^2+|b_n|^2\right]. \tag{14}$$

Although the cross sections account for the energy removed from the forward beam, they do not give any information about where the scattered photons go. This information is contained in scattering amplitudes and intensity factors which relate the flux density scattered through an angle θ relative to the incident flux density. There are two amplitudes, $S_1(\theta)$ and $S_2(\theta)$, and the intensity factors $i_1(\theta)$ and $i_2(\theta)$, which correspond to light respectively polarized perpendicular and parallel to the plane of the scattering defined by the direction of incidence and the direction of scattering.

The intensity factors are related to the scattering amplitudes by

$$i_1(\theta) = |S_1(\theta)|^2, \tag{15}$$

and

$$i_2(\theta) = |S_2(\theta)|^2. \tag{16}$$

The amplitudes come from the multipole moments through

$$S_1(\theta) = \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} [a_n \pi_n(\theta) + b_n \tau_n(\theta)], \tag{17}$$

and

$$S_2(\theta) = \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} [b_n \pi_n(\theta) + a_n \tau_n(\theta)], \tag{18}$$

and angular factors $\pi_n(\theta)$ and $\tau_n(\theta)$ defined in terms of associated Legendre functions:

$$\pi_n(\theta) = P_n^1(\cos\theta)/\sin\theta; \tag{19}$$

$$\tau_n(\theta) = \frac{dP_n^1(\cos\theta)}{d\theta} \quad . \tag{20}$$

The amplitudes have relative phase $\delta = \arg S_1 - \arg S_2$.
Alternative expressions frequently used are

$$\pi_n(\theta) = \frac{dP_n(\cos\theta)}{d(\cos\theta)} , \tag{21}$$

and

$$\pi_n(\theta) = \cos\theta \cdot \pi_n(\theta) - \sin^2\theta \cdot \frac{d\pi_n(\theta)}{d(\cos\theta)} , \tag{22}$$

where

$$P_n(\cos\theta) = \frac{1}{2^n n!} \frac{d^n}{d\cos^n\theta} (\cos^2\theta - 1)^n \quad . \tag{23}$$

These functions satisfy the following recurrence relations:

$$\pi_n(\theta) = \cos\theta \frac{(2n-1)}{(n-1)} \pi_{n-1}(\theta) - \frac{n}{n-1} \pi_{n-2}(\theta), \qquad (24)$$

and

$$\tau_n(\theta) = \cos\theta [\pi_n(\theta)-\pi_{n-2}]-(2n-1)\sin^2\theta\pi_{n-1}(\theta)+\tau_{n-2}(\theta) . \qquad (25)$$

The scattering cross section measures the ability of a particle to scatter light, and it is to be expected that C_{sca} is obtained from an integral over the scattering intensity factors. Equation (12) follows from

$$C_{sca} = \frac{\lambda^2}{4\pi} \int_{-1}^{1} [i_1(\theta) + i_2(\theta)] \, d\cos\theta. \qquad (26)$$

Although the intensity factors themselves may be used in scattering calculations, they are primarily suited for computing flux densities, and it is frequently more convenient to measure and compute scattered light in terms of radiances. Radiances do not have the $1/r^2$ dependence, and it is therefore unnecessary to know the distance from the scatterer to the detector if the detector field of view is small and is filled by the scattering cloud. The phase function, $p(\theta)$, gives a radiance, I, scattered into the θ direction in terms of the radiance I_o incident on the particle. The phase function is dimensionless and is defined here as

$$p(\theta) = \frac{\lambda^2}{2\pi C_{ext}} [i_1(\theta) + i_2(\theta)]. \qquad (27)$$

The normalized phase function $p(\theta)d\Omega/4$ gives the probability of a photon being scattered through an angle θ into an element of solid angle $d\Omega = d\phi d(\cos\theta)$. The integral of the normalized phase function is the single scattering albedo $\tilde{\omega}_o$, which gives the probability that the photon is scattered:

$$\tilde{\omega}_o = \frac{1}{4\pi} \int_0^{2\pi} \int_{-1}^{1} p(\theta) d\phi d\cos\theta = \frac{\lambda^2}{4\pi C_{ext}} \int_{-1}^{1} [i_1(\theta)+i_2(\theta)] d\cos\theta, \qquad (28)$$

or

$$\tilde{\omega}_o = C_{sca}/C_{ext} . \qquad (29)$$

The phase function contains a sum over the polarization states implicit in the i_1 and i_2 intensity factors, and is thus unsuitable for describing the polarization of the scattered light.

The phase function can also be represented by a Legendre series:

$$p(\theta) = \sum_{\ell=0}^{n-1} \tilde{\omega}_\ell P_\ell(\cos\theta), \qquad (30)$$

where the Legendre expansion coefficients $\tilde{\omega}_\ell$ are given by

$$\tilde{\omega}_\ell = \frac{(2\ell+1)}{2} \int_{-1}^{1} p(\theta) P_\ell(\cos\theta) d(\cos\theta), \qquad (31)$$

and $P_\ell(\cos\theta)$ are the usual Legendre polynomials.

ANALYTIC PHASE FUNCTION

A new analytic phase function has been constructed that approximates the computed phase function. This analytic phase function is comprised of two analytic functions; a new function up to angle θ_1 and a modified Henyey - Greenstein analytic function for angles greater than θ_1. This new analytic phase function is called the Goedecke-Henyey-Greenstein analytic phase function and will subsequently be referred to as the GHG phase function.

The GHG phase function has the following analytic form:

$$\bar{p}(\mu) = \begin{cases} \tilde{\omega}_o \left[\frac{\alpha}{2} \frac{1-g^2}{(1-2g\mu+g^2)^{3/2}} + \left(1-\frac{\alpha}{2}\right) \frac{1}{(1-2g\mu+g^2)^{1/2}} \right], & 1 \geq \mu \geq \mu_1, \\ \tilde{\omega}_o \, \beta \frac{1-g^2}{(1-2g\mu+g^2)^{3/2}}, & \mu_1 \geq \mu \geq -1, \end{cases} \qquad (32a,b)$$

where $\mu = \cos\theta$, $\tilde{\omega}_o$ is the albedo for single scattering, and $\bar{P}(\mu)$ is the phase function at μ. The bar above quantities denotes approximations. Here, g, α, β, μ_1 are parameters that must be fixed and are evaluated as follows:

Using equation 32a as a generating function, we may write the equivalent equation

$$\overline{P}(\mu) = \tilde{\omega}_o \sum_{N=0}^{\infty} (\alpha N+1) g^N P_N(\mu), \tag{33a}$$

or

$$\overline{P}(\mu) \equiv \sum_{N=0}^{\infty} \overline{\omega}_N P_N(\mu), \tag{33b}$$

where the $P_N(\mu)$'s are the Legendre polynomials, and again the bar above the symbols denotes approximations. Making use of equations 32a and 33a we now solve for α and β by forcing the equations to match at $\mu = 1$. This is done because forward scattering is usually dominant for large Mie size parameters. Solve simultaneously

$$\overline{P}(1) = \frac{\tilde{\omega}_o}{(1-g)^2} \left[\frac{\alpha}{2} (1+g) + (1- \frac{\alpha}{2})(1-g)\right], \tag{34a}$$

$$\tilde{\omega}_2 = \bar{\omega}_2 = \tilde{\omega}_o \ (\alpha + 1)g^2. \qquad (34b)$$

In equation (34b) we have forced the approximate value, $\bar{\omega}_2$, to equal the exact value, $\tilde{\omega}_2$. $\tilde{\omega}_2$ has been used, as opposed to $\tilde{\omega}_1$, as it was found that the match produced by $\tilde{\omega}_1 = \tilde{\omega}_o(\alpha+1)g$ will not work for all cases. Since we expect that for $\mu < \mu_1$ the actual phase function, and therefore the HG part of the GHG phase function, is small compared to its values for $\mu > \mu_1$, we take the values of α and g, found by simultaneously solving equations 34a and b, as our working values.

Ideally μ_1 could be found by setting equation 34a equal to zero; however, using a value of μ_1 determined in such a manner would produce an unnatural dip in the phase function where we match 32a to 32b. Therefore we take μ_1 to be that value of μ for which the phase function represented by equation (32a) first goes negative (the phase function represented by equation 32a may not go negative, but dependent upon the various parameters it may). β is found by matching 32a to 32b at $\mu = \mu_1$. This yields

$$\beta = \frac{\alpha}{2} + (1 - \frac{\alpha}{2})(1-2g\mu_1+g^2)/(1-g^2) > 0. \qquad (35)$$

Since μ_1 is now known a priori the value of β will be approximate. As $\beta > 0$ then $\bar{P}(\mu) > 0$ for all μ and is a continuous function of μ. We must now determine the approximate Legendre coefficients, $\bar{\omega}_N$. This is done by using the inversion formula

$$\bar{\omega}_N = \frac{2N+1}{2} \int_{-1}^{1} \bar{P}(\mu) P_N(\mu) d\mu. \tag{36}$$

If $\mu_1 > -1$, implying usage of the HG phase function, none of the $\bar{\omega}_N$ will exactly match the exact or 'true' $\tilde{\omega}_N$. Since it is most important that an approximate phase function have the correct single scattering albedo, $\tilde{\omega}_o$, we redefine

$$\bar{P}(\mu) \equiv \frac{\tilde{\omega}_o}{\bar{\omega}_o} \bar{P}(\mu), \tag{37}$$

and therefore,

$$\begin{aligned} \bar{\omega}'_N &= \frac{2N+1}{2} \int_{-1}^{1} \bar{P}(\mu) P_N(\mu) d\mu, \\ &= \frac{\tilde{\omega}_o}{\bar{\omega}_o} \varpi_N. \end{aligned} \tag{38}$$

This guarantees that $\bar{\omega}_o = \tilde{\omega}_o$, but because α, g, and β are approximate, $\bar{\omega}_2$ will not match $\tilde{\omega}_2$ exactly. As long as the HG part of the GHG phase is small, the mismatch between $\bar{\omega}_2$ and $\tilde{\omega}_2$ will be small.

In all the above cases it is necessary to calculate only two of the coefficients in the Legendre expansion of the phase function, $\tilde{\omega}_o$ and $\tilde{\omega}_1$ or $\tilde{\omega}_o$ and $\tilde{\omega}_2$. This may be done directly in terms of the a_n and b_n coefficients of the Legendre series occurring in Mie theory without evaluating the exact phase function of any angle.

We want the phase function incident for natural light to satisfy

$$\int_{-1}^{1} \bar{P}(\mu)d\Omega = 4\pi\tilde{\omega}_o = 2\pi \int_{-1}^{1} P(\mu)d\mu = 4\pi \frac{C_{scat}}{C_{ext}}, \tag{39}$$

where C is the total cross section for scattering and extinction, respectively. In the notation of van de Hulst[4]

$$C_{scat} = \frac{1}{k^2} \int F(\theta,\phi)d\Omega. \tag{40}$$

So, if we put

$$P(\mu) = \frac{K}{2\pi} \int_{o}^{2\pi} F(\theta,\phi)d\phi, \tag{41}$$

then

$$\int P(\mu)d\Omega = K\, k^2\, C_{scat}, \tag{42}$$

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[4]H. C. van de Hulst, 1957, Light Scattering by Small Particles, John Wiley and Sons, Inc., New York

or

$$K = \frac{4}{k^2 C_{ext}} , \tag{43}$$

and therefore

$$P(\mu) = \frac{2}{k^2 C_{ext}} \int_0^{2\pi} F(\theta,\phi)d\phi. \tag{44}$$

Now $F(\theta,\phi) = i_1(\theta)\sin^2\phi + i_2(\theta)\cos^2\phi$, hence

$$P(\mu) = \frac{1}{k^2 C_{ext}} [i_1(\theta) + i_2(\theta)], \tag{45}$$

where $i_{1,2}(\theta) = |S_{1,2}(\theta)|^2$

and

$$S_1(0) = S_2(0) = \frac{1}{2} \sum_{n=1}^{L\to\infty} (2n+1)(a_n+b_n). \tag{46}$$

Therefore,

$$P(1) = \frac{1}{k^2 C_{ext}} \frac{1}{2} \left| \sum_{n=1}^{L} (2n+1)(a_n+b_n) \right|^2 = \frac{2}{k^2 C_{ext}} \left| S_1(0) \right|^2, \qquad (47)$$

where

$$C_{ext} = \frac{4\pi}{k^2} \mathrm{Re}\left[\frac{1}{2} \sum_{n=1}^{L\to\infty} (2n+1)(a_n+b_n) \right] = \frac{4\pi}{k^2} \mathrm{Re}\ [S_1(0)]. \qquad (48)$$

This allows direct calculation of P(1) in terms of a_n and b_n. We now need expressions for $\tilde{\omega}_1$ and/or $\tilde{\omega}_2$ in terms of the a_n and b_n. These are given by Chu and Churchill.[5*] In terms of the Mie coefficients a_n, b_n, these expressions are:

$$\tilde{\omega}_1 = \frac{3}{x^2 Q_{ext}} \sum_{n=1}^{\infty} \left[\frac{2n(n+2)}{(n+1)} (a_n a_{n+1}^* + b_n b_{n+1}^* + a_{n+1} a_n^* + b_{n+1} b_n^*) + \frac{2(2n+1)}{n(n+1)} (a_n b_n^* + a_n^* b_n) \right], \qquad (49)$$

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[5]C. M. Chu and S. W. Churchill, 1955, "Representation of the Angular Distribution of Radiation Scattered by a Spherical Particle," J Opt Soc Am, 45:958

*There appears to be a typographical error in Chu and Churchill's work on the bottom of page 961: j+k-n = 2r+1 should read j+k-n = 2r-1.

$$\tilde{\omega}_2 = \frac{4}{x^2 Q_{ext}} \sum_{n=1}^{\infty} \left[\frac{5}{2} \frac{(n(n+1)-3)^2(2n+1)}{n(n+1)(2n+3)(2n-1)} \mathrm{Re}(a_n^* a_n + b_n^* b_n)\right.$$

$$\left. + \frac{15}{2} \frac{n(n+3)}{(2n+3)} \mathrm{Re}(a_{n+2}^* a_n + b_{n+2}^* b_n) + \frac{15}{n+1} \mathrm{Re}(a_{n+1}^* b_n + b_{n+1} a_n^*)\right] , \tag{50}$$

where $x = 2\pi r/\lambda$, $Q_{ext} = C_{ext}/(\pi r^2)$, and r is the particle radius.

RELATIONSHIPS BETWEEN SCATTERING FRACTIONS AND PHASE FUNCTIONS

Among the objectives of the work done here was the conversion of the single scattering code AGAUS into a form which produced the types of data required by the ACT Battlefield/Smoke Obscuration Model while retaining a variety of options previously developed for AGAUS. That conversion required that AGAUS be given the additional capabilities of predicting (a) attenuation coefficients or cross sections in units of square meters per milligram of aerosol material, and (b) so-called "scattering fractions" per unit aerosol mass. In order to avoid possible confusions on the precise relationships between "scattering fractions" and the customary quantities used in Mie theory, those relationships will be summarized below before proceeding to a discussion of the evaluation of AGAUSX.

The so-called "phase functions", denoted here by $P_f(\mu)$ and "scattering fractions" $S_f(\theta)$ are both derived from the average scattered intensities $(I_1 + I_2)/2$ defined in Mie theory. The two quantities are related to one another for calculations associated with a single wavelength by a simple multiplicative factor, but they have different interpretations and applications.

Let $I(\alpha, m, k, \theta)$ be the average of the intensities $i_1(\theta)$ and $i_2(\theta)$ for scattering at angle θ from a sphere whose Mie-size parameter is $\alpha = 2\pi r/\lambda$, and whose complex index of refraction is $n = m-ik$. Furthermore, let $n(r)dr$ be the relative number of aerosol particles with radii between r and $(r+dr)$, and let $Q_{ext}(\alpha,m,k)$ and $Q_{sca}(\alpha,m,k)$ respectively be the total extinction and

scattering efficiency factors as defined by van de Hulst.[4]

Now, define the quantities $\bar{I}$, $\bar{C}_{ext}$ and $\bar{C}_{sca}$ as follows:

$$\bar{C}_{ext} = \frac{1}{N_T} \int_{r=o}^{\infty} \pi r^2 n(r)\ Q_{ext}(\alpha,m,k)dr, \tag{51}$$

$$\bar{C}_{sca} = \frac{1}{N_T} \int_{r=o}^{\infty} \pi r^2 n(r)\ Q_{sca}(\alpha,m,k)dr, \tag{52}$$

$$\bar{I}(\theta) = \frac{1}{N_T} \int_{r=o}^{\infty} I(\alpha,m,k,\theta)n(r)dr, \tag{53}$$

where

$$N_T = \int_{r=o}^{\infty} n(r)dr. \tag{54}$$

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[4]H. C. van de Hulst, 1957, Light Scattering by Small Particles, John Wiley and Sons, Inc., New York

The "phase function" as defined in program(s) AGAUS is given by

$$P_f(\theta) = \frac{\lambda^2}{\pi \bar{C}_{ext}} \bar{I}(\theta) \ , \tag{55}$$

as has the property that

$$\int_{\phi=o}^{2\pi} \int_{\theta=o}^{\pi} P_f(\theta) d\phi \ d(\cos\theta) = 4\pi \frac{\bar{C}_{sca}}{\bar{C}_{ext}} \equiv 4\pi\tilde{\omega}_o \ , \tag{56}$$

where $\tilde{\omega}_o$ is called "the albedo for single scattering".

The "scattering fractions" $S_f(\theta)$ are defined by

$$S_f(\theta) = \left(\frac{\lambda}{2\pi}\right)^2 N_T \bar{I}(\theta), \tag{57}$$

and $S_f(\theta)$ has the property

$$\int_{\phi=o}^{2\pi} \int_{\theta=o}^{\pi} S_f(\theta) d\phi d(\cos\theta) = \bar{C}_{sca} \cdot N_T = (C_{sca})_{total}, \tag{58}$$

wherein $(C_{sca})_{total}$ is the total scattering cross section per unit mass of aerosol material.

Thus, it will be seen that

$$S_f(\theta) = (\frac{1}{4\pi} N_T \overline{C}_{ext}) P_f(\theta). \quad (59)$$

The ACT Model is coded with the assumption that $(C_{sca})_{total}$ as derived from $S_f(\theta)$ will have units of square meters per milligram. Programs AGAUS9 and AGAUSX, (see below) on the other hand are coded in what are basically CGS units. Conversion from $I(\theta)$ to $S_f(\theta)$ in the ACT normalization therefore requires a unit-conversion factor for λ^2 from μm to m, and for N_T from cm^{-3} to m^{-3}, i.e.,

$$[\lambda(\mu m)]^2 N_T(cm^{-3}) \times (10^{-6} \frac{m}{\mu m})^2 \times 10^6 \frac{cm^3}{m^3} . \quad (60)$$

Thus, a factor 10^{-6} is required to convert the scattering fractions from the internal units of program AGAUS to the units expected by ACT.

VERIFICATION OF COMPUTER CODES

Evaluation of AGAUS9:* Once the relationships between the Mie intensities, i_1 and i_2 described above were clearly eluciated, it seemed that it would be a straightforward task to convert AGAUS from the computation of phase functions to the calculation of scattering fractions. When the appropriate conversions were completed, the new version, AGAUS9, was run using, as nearly as could be

*AGAUS9 is the parent code for AGAUSX and they basically differ only in the manner in which the number of radial increments for integration over the size distributions are chosen.

determined, the same aerosol model for which results were found in the ACT documentation.* The particular model used was a log normal distribution for white phosphorus (WP) smoke ($\bar{r}$ = 0.37μm, σ - 1.54μm), 200 particle radii between minimum and maximum values of 0.005 and 1.0μm, respectively, a mass density of 1.87 gm/cc, a particle number density of 1.276345×10^3 cm^{-3}, and complex index of refraction n = 1.43 - 0i. Computations were performed at 7 wavelengths (0.40, 0.45, 0.50, 0.55, 0.60, 0.65 and 0.70μm), and the scattering fractions were arithmetically averaged over wavelength. Some of the results are presented in table 1. Only a cursory examination of that table is needed to observe that the AGAUS9 results were not in very good agreement with those found in the ACT documentation. This comparison was unexpected, because the basic AGAUS code had previously been found to give much better agreement with other Mie codes than is seen in table 1.

Because thorough reviews of the program listings failed to shed any light on the reasons for such large apparent discrepancies it was decided that comparisons of computations made at a single wavelength (rather than after averaging over several wavelengths) were highly desirable. The problem there was that the ACT documentation did not contain any single wavelength results. Since that avenue for testing of AGAUS9 was closed, some other approach was needed, and was found through a copy of the MIE2 code.

The aerosol model used to generate table 1 was then passed through both AGAUS9 and the MIE2 code using a wavelength of 0.40μm only. The results of those two runs are shown in table 2.**

Examination of table 2 reveals that the AGAUS9 results and the MIE2 results are in much better agreement than those seen in table 1. Whereas table 2 shows discrepancies even in the first digit at many scattering angles, table 2

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*The label ACT is used to refer to the document entitled "The Effectiveness of Obscuring Smokes," by Johnson, Forney and Dolce, and unpublished description of the JTCG/ME smoke obscuration model which was obtained from R. B. Gomez of ASL.

**The results of MIE2 have been multiplied by a factor of 10^2 to offset different normalizations used in ACT and AGAUS9.

TABLE 1

COMPARISON OF SCATTERING FRACTIONS FROM AGAUS9

AND ACT REPORT AS AVERAGED FOR A SEVEN WAVELENGTH RUN

Scattering Angle	Scattering Fractions	Scattering Fractions ACT Report
0°	0.5840074-02	0.530822-02
10°	0.3385669-02	0.294243-02
20°	0.1236144-02	0.961893-03
30°	0.5525204-03	0.419528-03
40°	0.2882904-03	0.254840-03
50°	0.1637546-03	0.176892-03
60°	0.9840574-04	0.114931-03
70°	0.6277324-04	0.706178-04
80°	0.4262488-04	0.445657-04
90°	0.3097364-04	0.309732-04
100°	0.2429897-04	0.249208-04
110°	0.2086846-04	0.237614-04
120°	0.2023009-04	0.265251-04
130°	0.2267312-04	0.330425-04
140°	0.3014750-04	0.446135-04
150°	0.4592933-04	0.637035-04
160°	0.6781825-04	0.883152-04
170°	0.4512012-04	0.678717-04
180°	0.6003613-04	0.836141-04

TABLE 2

COMPARISON OF RESULTS FROM RUNS OF AGAUS9

AND MIE2 AT A SINGLE WAVELENGTH

Scattering Angle	Scattering Fractions	I^*_{avg}(MIE2)
0°	8.215439-03	8.215442-03
10°	3.341243-03	3.341238-03
20°	8.565565-04	8.565530-04
30°	4.126651-04	4.126640-04
40°	2.452253-04	2.452247-04
50°	1.503114-04	1.503111-04
60°	9.399925-05	9.399906-05
70°	6.098411-05	6.098398-05
80°	4.167272-05	4.167267-05
90°	3.019892-05	3.019886-05
100°	2.333270-05	2.333268-05
110°	1.957286-05	1.957282-05
120°	1.854355-05	1.854351-05
130°	2.096545-05	2.096542-05
140°	2.942918-05	2.942910-05
150°	4.947500-05	4.947498-05
160°	8.643879-05	8.643865-05
170°	6.208783-05	6.208780-05
180°	7.644555-05	7.644557-05

*The MIE2 results have been multiplied by 10^2 to normalize them in the same way as found in the SOM document.

shows that AGAUS9 and MIE2 agree to at least give and often six significant digits--the nominal accuracy which is used in terminating Mie series calculations in AGAUS9. The disagreements found in table 1 should be interpreted as differences either in the procedure for the integration over wavelength or the fact that a single precision version of MIE2 was used in the generation of the ACT data.

To avoid drawing erroneous conclusions on the cross-agreements between results produced by AGAUS9 and MIE2 on the basis of a single aerosol model, additional comparisons were made using a quite different aerosol model. The model chosen for this "test" was a "modified" gamma distribution:

$$f(r) = Ar^{\alpha} \exp(-Br^{\gamma}), \qquad \text{[for MIE2]} \tag{61}$$

with $A = 1.0396 \times 10^{8}$, $\alpha = 7.5$, $B = 333333$ and $\gamma = 1.0$. The input data used by AGAUS9 are the particle number density N_T and mode radius r_c, rather than A and B, but the various quantities are related to one another through:

$$r_c = \left(\frac{\alpha}{\gamma B}\right)^{1/\gamma} \quad \text{and} \quad N_T = AB^{-\left(\frac{\alpha+1}{\gamma}\right)} \Gamma\left(\frac{\alpha+1}{\gamma}\right) . \tag{62}$$

For this comparison the minimum and maximum particle radii were taken to be 0.01μm and 1.5μm, respectively, and 200 individual values of particle radii were used. The run was made at a wavelength of 0.6μm using $n = 1.53 - 0.006i$. Some results of the first runs of this type will be found in table 3.

Contrary to the excellent agreement found between MIE2 and AGAUS9, the data found in table 3 did not agree as well as had been expected being good only to about 4 digits. Further analysis indicated that the most probable source of these disagreements lay in the fact that AGAUS9 and MIE2 did not choose the

TABLE 3

COMPARISON OF SCATTERING FRACTIONS CALCULATED BY MIE2 AND AGAUS9 FOR A MODIFIED GAMMA DISTRIBUTION

Scattering Angle	Scattering Fractions	I^*_{avg}(MIE2)
0°	9.254421-08	9.254768-08
10°	7.620680-08	7.620913-08
20°	4.470319-08	4.470374-08
30°	2.156754-08	2.156747-08
40°	1.038258-08	1.038255-08
50°	5.626184-09	5.626226-09
60°	3.415889-09	3.415935-09
70°	2.236736-09	2.236776-09
80°	1.555144-09	1.555170-09
90°	1.149602-09	1.149602-09
100°	9.113908-10	9.114065-10
110°	7.876338-10	7.876470-10
120°	7.656564-10	7.656688-10
130°	8.657526-10	8.657658-10
140°	1.074210-09	1.074245-09
150°	1.193137-09	1.193200-09
160°	1.134702-09	1.134755-09
170°	1.502157-09	1.502236-09
180°	1.969069-09	1.969203-09

*The MIE2 results have been multiplied by 10^2 to normalize them in the same way as found in the ACT document.

values of particle radii actually used in the calculation in the same way. Slight alterations to remove these differences were then made in AGAUS9, and the calculations were repeated, yielding the data presented in table 4.

In table 4 discrepancies between the AGAUS9 and MIE2 results again appear only in the fifth or sixth significant digit.

The above results indicate once again that code AGAUS9 is quite capable of yielding results which are as reliable as those of MIE2. The changes in AGAUS9 needed to bring about the level of agreement seen in table 4 involved only the choice of the values of the 200 radii used, and illustrates that the method of choosing the radii can have a significant effect on the values of the scattering fractions even when a relatively large number of radii are used. The matter will be discussed further in a subsequent section of this document.

EVALUATION OF PROGRAM AGAUSX

Introduction: In the development of the actual coding of program AGAUSX, continuous testing and comparison of results produced by the new codes and those yielded by other single scattering codes was carried out. The findings of a few such comparisons will be given next.

The supplementary codes used for evaluation of AGAUSX were the codes AGAUS9, and the code MIE2. In order to avoid the problem of deciding which of the three codes used was "correct" in the event that no two agreed well, all codes were run using aerosol models for which independent results could be found in Deirmendjian's book.[6] The specific models used for comparison runs were Deirmendjian's cloud models C.1 and C.3 at a wavelength of 0.7μm. Additional comparison runs were made at 10.6μm using a simulated hygroscopic smoke model[7]

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[6]D. Deirmendjian, 1969, Electromagnetic Scattering on Spherical Polydispersions, American Elsevier Publishing Co., Inc., New York

[7]A. Miller, R. C. Shirkey, E. Gemoets and G. H. Goedecke, 1978, Investigations on the Prediction of Infrared Transmission and Emission by Clear and Aerosol Laden Atmospheres, NMSU Department of Physics, Final Report for Contract DAEA18-77-C-00003

TABLE 4

COMPARISON OF SCATTERING FRACTIONS PRODUCED BY MIE2 AND A SPECIAL VERSION† OF AGAUS9 FOR A MODIFIED GAMMA DISTRIBUTION

Scattering Angle	Scattering Fractions	I^*_{avg}(MIE2)
0°	9.254772-08	9.254768-08
10°	7.620918-08	7.620913-08
20°	4.470380-08	4.470374-08
30°	2.156751-08	2.156747-08
40°	1.038257-08	1.038255-08
50°	5.626233-09	5.626226-09
60°	3.415938-09	3.415935-09
70°	2.336777-09	2.336776-09
80°	1.555171-09	1.555170-09
90°	1.149623-09	1.149622-09
100°	9.114071-10	9.114065-10
110°	7.876480-10	7.876470-10
120°	7.656697-10	7.656688-10
130°	8.657668-10	8.657658-10
140°	1.074245-09	1.074245-09
150°	1.193200-09	1.193200-09
160°	1.134755-09	1.134755-09
170°	1.502236-09	1.502236-09
180°	1.969203-09	1.969203-09

†Particle radii selected the same way as in MIE2.

*The MIE2 results have been multiplied by 10^2 to normalize them in the same way as found in the SOM document.

and several values of relative humidity. The latter comparisons involved only program AGAUS9 and AGAUSX. The objectives of all comparisons were not only to show that AGAUSX was working properly, but also to determine whether or not it would, in fact, offer significant reductions in overall running time.

Water Cloud Model Comparisons: Comparison runs of codes AGAUS9, AGAUSX and MIE2 for cloud models C.1 and C.3 were made using the same range of radii quoted for Deirmendjian's tables T.36 and T.30. In order to assure that any conclusions drawn about relative computation times would be valid in the context of ACT usage, scattering fractions were calculated at 2° increments between scattering angles of 0° and 180° in these runs. AGAUSX was also run for model C.1 using several different values of the convergence level DELTA.

Table 5 presents some of the results obtained for cloud model C.1. The scattering fraction entries for the "Deirmendjian" column were obtained by averaging his P_1 and P_2, and multiplying by the appropriate conversion factor. The AGAUSX run listed used DELTA = 0.01. Examination of the tabulated data shows that none of the three runs yields exactly the same extinction coefficient that was printed by Deirmendjian, but all were within 0.3 percent of his results. Unfortunately, Deirmendjian's table T.36 did not include angles at 2° increments, so only forward and backward scattering fractions could be inferred accurately. It will be seen that all three codes gave scattering fractions which agreed well in the $\theta = 0°$ direction, but the results are obviously not identical. The variations are, however, quite a bit larger at other scattering angles, although the variations are not terribly large when their magnitudes are compared to that of the forward scattering. For this particular model, it will be noted that AGAUSX convergence criterion led to its use of more radii than were used with the other codes. It will also be seen that MIE2 handled the 40 radii faster than did AGAUS9. MIE2's speed advantage over AGAUS9 probably results from the fact that MIE2 used non-uniform spacing of particle radii--a procedure which leads to a significantly smaller number of Mie calculations which must be done ar large Mie size-parameters.

TABLE 5

COMPARISONS OF RESULTS AND CPU TIMES FOR THREE SINGLE SCATTERING CODES - CLOUD MODEL C.1. (λ = 0.7μm)

Quantity	AGAUS9	AGAUSX (Delta-0.01)	MIE2	Deirmendjian T.36
$K_{ext}(km^{-1})$	16.7512	16.7223	16.780	16.73
$K_{sca}(km^{-1})$	16.7512	16.7223	16.780	16.73
Scattering Fractions				
θ				
0°	2.2438EO	2.2404EO	2.2534EO	2.237EO
44°	1.952E-3	1.784E-3	1.0875E-3	
90°	6.1552E-5	4.8011E-5	5.6898E-5	
136°	1.8252E-4	1.9026E-4	2.1120E-4	
180°	8.9722E-4	8.3856E-4	8.9161E-4	8.457E-4
CPU Time (Seconds)	86.86	82.81	75.35	
No. of Radii	40	50	40	440

*NOTE: AGAUS9 and AGAUSX scattering fractions at 0°, when converted to phase functions have values of 1683, as compares to Deirmendjian's values of 1680.

It should be noted that the version of AGAUSX used in generating results shown in table 5 performed its "convergence test" on the total aerosol volume and not on the scattering fractions. (Results obtained by checking on both volume and the scattered intensity at 90° will be given below.)

Although AGAUSX appears to offer no computation speed advantage if the user knows how many radii are "enough", it does have the useful feature (not found in either MIE2 or AGAUS9) of giving the user some idea of how many radii were really required to achieve some minimum level of confidence in its results.

By repeating runs of AGAUSX and model C.1 using various values of DELTA, it has been possible to learn more about the sensitivities of the extinction coefficient and scattering fractions to the number of radii used in a calculation. Table 6 contains the results of a few runs of that type. The first four entries represent runs in which the quantity which was tested for convergence was the total volume of the aerosol particles.* The fifth and sixth entries are the results of runs in which testing was done on both volume and the scattered intensity at 90°; note that the sixth entry represents a run at 45° increments rather than 2° increments.

Examination of table 6 shows that the value of the extinction coefficient is not nearly as sensitive to the choice of particle radius values as are the scattering fractions at fairly large scattering angles, especially near 90°. The 90° results show "oscillations" of as much as 15 percent as the number of radii changes through the set {26, 50, 66, 98, 130, and 513}.

It should also be noted that AGAUS9 and MIE2 runs shown in table 5 used only 40 radii, while Deirmendjian evidently used 440 radii. Even with that vastly larger number of radii, Deirmendjian's results are not so different from the present results to warrant, in many applications, an additional increase in computation time of a factor of eleven.

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*Volume was used rather than extinction cross-section because its R^3 dependence appeared to make it a "more sensitive" test quantity.

TABLE 6

COMPARISON OF AGAUSX RESULTS OBTAINED WITH FOUR CONVERGENCE TEST LEVELS

USING CLOUD MODEL C.1. (λ = 0.7μm)

Convergence Level	NRADI	CPU (Seconds)	K_{ext} (km^{-1})	Scattering Fractions				
				0°	44°	90°	136°	180°
0.05	26	45.28	17.47	2.4521EO	1.1280E-4	5.2019E-5	1.8805E-4	7.4914E-4
0.01	50	82.81	16.72	2.2404EO	1.1784E-3	4.8011E-5	1.9026E-4	8.3856E-4
0.005	66	127.93	16.74	2.2395EO	1.1697E-3	5.6570E-5	1.9095E-4	8.7430E-4
0.001	130	245.13	16.73	2.2370EO	1.1815E-3	5.4473E-5	1.8960E-4	8.2393E-4
*0.05	98	220.91	16.73	2.2369EO	1.1814E-3	5.5012E-5	1.9213E-4	8.3975E-4
**0.005	513	143.73	16.75	2.2411EO		5.5880E-5		8.8647E-5

NOTES: (a) In these runs, the quantity which was tested for convergence was the total volume of the aerosol particles.

(b) In these runs, scattering fractions were calculated at 2° increments.

*Special Version of AGAUSX with convergence checks on scattered intensity at 90° as well as on volume.

**Similar to * case, but only 5 angles used.

A similar set of comparative results obtained for cloud model C.3 are presented in table 7. For this model, AGAUS9 and MIE2 were run with the same number of radii as was used by Deirmendjian. This example illustrates the way in which AGAUSX can offer definite decreases in CPU time over codes requiring the user to make an a priori decision as to the number of radii needed. Using only 66 radii, AGAUSX produced an extinction coefficient to within better than 1 percent of Deirmendjian's value (with which AGAUS9 and MIE2 results are identical to the four digits given by Deirmendjian). AGAUSX, (with DELTA = 0.01), however, ran nearly four times faster than either AGAUS9 or MIE2. Furthermore, the AGAUSX run at DELTA = 0.01 yielded scattering fractions which, at worst, differed from those found by AGAUS9 and MIE2 by the order of 10 percent.

Cloud models such as C.1 and C.3 used at short wavelengths ($\approx$ visible) are severe tests of single scattering codes because they typically involve some rather large Mie size-parameters ($\alpha \approx 110$ for the C.1 model). Calculations performed at infrared wavelengths for smaller particles than found in typical clouds are not quite so demanding. That fact is illustrated partially, by tables 8 and 9, which were compiled using a hypothetical model for a hygroscopic smoke having the particle size-distribution of white phosphorous smoke. The model used here was denoted as model A' in an earlier document.[7] Table 8 shows extinction coefficients obtained from AGAUS9 (using 100 radii), and AGAUSX (using DELTA = 0.01) at seven different values of relative humidity. It also presents the results of a run of a special version of AGAUSX (labeled AGAUSXL) in which the Mie routine DOWN42 was used instead of routine MIEGX. It will be seen that AGAUSX (and AGAUSXL) needed only 34 radii to reach extinction coefficients within 0.2 percent of those found by AGAUS9, but the AGAUS9 run used 340 percent more computer time than did AGAUSX. AGAUSXL's results were quite close to those of AGAUSX, but the relative slowness of DOWN42 brought the total time to treat 34 radii up to nearly the same time needed by AGAUS9 to treat 100 radii.

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[7] A. Miller, R. C. Shirkey, E. Gemoets and G. H. Goedecke, 1978, Investigations on the Prediction of Infrared Transmission and Emission by Clear and Aerosol Laden Atmospheres, NMSU Department of Physics, Final Report for Contract DAEA18-77-C-00003

TABLE 7

COMPARISONS OF RESULTS AND CPU TIMES FOR THREE SINGLE SCATTERING CODES -

CLOUD MODEL C.3 (λ = 0.7μm)

Quantity	AGAUS9	AGAUSX*		MIE2	Deirmendjian T.60
		Δ = .01	Δ = .001		
$K_{ext}(km^{-1})$	3.0212	3.0078	3.0151	3.0218	3.021
$K_{sca}(km^{-1})$	3.0212	3.0078	3.0151	3.0218	3.021
Scattering Fractions*					
θ					
0°	5.3970E-2	5.3569E-2	5.3796E-2	5.3946E-2	5.396
44°	2.1276E-4	2.1398E-4	2.1220E-4	2.1182E-4	
90°	2.0787E-5	2.1668E-5	2.2180E-5	2.0366E-5	
136°	3.5852E-5	3.2756E-5	3.4983E-5	3.5562E-5	
180°	2.0350E-4	1.7792E-4	1.9798E-4	2.0269E-4	1.64
CPU Time* (Seconds)	289.79	71.49	131.5	266.36	
No. of Radii	280	66	130	280	280

*NOTES: (a) All runs calculated Scattering Fractions at 2° increments between 0° and 180°.

(b) The quantity tested for convergence was the total aerosol volume.

TABLE 8

COMPARISONS OF RESULTS FROM PROGRAMS AGAUS9 AND AGAUSX

FOR SMOKE MODEL A' AT λ = 10.6μm (Relative humidity = 0%)

		Extinction Coefficients (per km)		
Relative Humidity (percent)	AGAUS9 (100 radii)	AGAUSX (34 radii) [Delta - 0.01]	AGAUSXL (34 radii)	%Difference*
0	0.1838	0.1835	0.1835	0.16
75	0.2801	0.2797	0.2797	0.18
80	0.3020	0.3016	0.3016	0.17
85	0.3340	0.3335	0.3335	0.27
90	0.3887	0.3882	0.3882	0.15
95	0.5350	0.5343	0.5343	0.15
99	1.9295	1.9268	1.9268	0.15
TOTAL CPU TIME	34.34 sec	9.83 sec	34.98 sec	71.4

*NOTE: Percent differences are: $|(\text{AGAUS9} - \text{AGAUSX})/\text{AGAUS9}| \times 100$

TABLE 9

COMPARISON OF AGAUSX RESULTS FOR FOUR DIFFERENT CONVERGENCE LEVELS AND A SIMULATED SMOKE MODEL - λ = 10.6μm (Relative humidity = 0%)

Convergence Level (DELTA)	No. of Radii Used	$K_{ext}(km^{-1})$
.05	18	1.8277
.01	34	1.8353
.005	50	1.8345
.001	130	1.8377

Convergence Level (DELTA)	Scattering Fractions		
	$\theta = 0°$	$\theta = 90°$	$\theta = 180°$
.05	1.5574E-6	6.9366E-7	1.2326E-6
.01	1.5610E-6	6.9555E-7	1.2365E-6
.005	1.5605E-6	6.9533E-7	1.2361E-6
.001	1.5621E-6	6.9613E-7	1.2376E-6

Table 9 demonstrates how the user's choice of DELTA affected runs of the simulated smoke model at a relative humidity of 0 percent. For that model, changes in the number of radii from 18 to 130 (a factor of seven) did not change either the extinction coefficient or the scattering fractions by more than 0.3 percent.

Discussion: One of the decisions which had to be made for program AGAUSX was that of determining just which "quantity" or set of quantities should be used in the test for convergence to within the level DELTA. The one which was finally chosen was the total volume of the aerosol particles. The volume was chosen because, being dependent on the cube of the radii, it might be a little more conservative choice than the extinction coefficient, although, as seen in tables 5 and 6, it is a less conservative test quantity than the scattered intensity at $\theta = 90^0$. Present experience is limited, but the use of the volume seems to be a good compromise unless highly precise scattering fractions are needed. If the latter situation arises in a particular application, users of the code should have no difficulty in coding in their own preferred test quantity. The quantities which are available at present are extinction, scattering, backscattering cross sections, and the average intensities at various angles. Careful study of the source listing for subroutine AGXPT2 will reveal how such changes can be made.

A major surprise which was revealed by these studies was the fact that the code MIE2 used less computer time to handle cloud models C.1 and C.3 than AGAUS9 needed (for the same number of radii). The reason for the surprise was that the basic Mie routine DOWN42 used by MIE2 was known to be usually appreciably slower than routine MIEGX. It was in fact, that difference in speed which caused AGAUSXL (see above, and table 8) to require more than three times as long to treat the smoke model than AGAUSX needed. The reason for MIE2's evident computation time advantage over AGAUS9 has been alluded to above, and appears to be the result of the differences in the ways in which the values of radii (at which the Mie calculations are to be done) are chosen in the two codes. In MIE2, the interval between successive values of particle radius is doubled as each additional value is assigned (at least for the generalized Khirgian-Mazin distribution), while AGAUS9 uses a constant increment. The MIE2 method therefore uses far fewer large values of radius

than the AGAUS9 method does. That difference, and the fact that the time required within the Mie subroutines DOWN42 and MIEGX increases rapidly with the size to wavelength ratio, appears to account for MIE2's (small) running time advantage over AGAUS9. That difference in how the radii are chosen definitely accounts for the disagreements between the MIE2 and AGAUS9 values for the scattering fractions for cloud models C.1 and C.3 (that disagreement is quite appreciable in table 5 in some cases). The latter conclusion has been verified by direct runs with a version of AGAUS9 which uses the MIE2 method for choosing the radii (the AGAUS9/MIE2 disagreements moved out to the fifth or sixth digit). The running time on a UNIVAC 1108 of the special version of AGAUS9 was 240 seconds as compared to 266 seconds for MIE2, demonstrating that the use of fewer large radii significantly decreases running time.

The questions raised above are, however, made somewhat academic by AGAUSX for many applications requiring single scattering calculations because of AGAUSX's clear speed advantage in handling distributions for which no a priori guide as to how many radii will be "enough" is available.

SOME EFFECTS OF THE NUMER OF SIZE INTERVALS USED IN AGAUSX

In the early development of AGAUSX, it was tentatively assumed that computation times might be substantially reduced by breaking the total ranges of radius values to be treated into more than one "size-interval" and then performing the halving calculations and tests separately within each size interval. That assumption was based upon the belief that the use of a single interval could result in unneeded computations in some size ranges brought about by slow convergence in other ranges. Consequently, all types of distribution functions which were known to be "peaked" were split into two size intervals: (a) one with radii smaller than the one at which the distribution was a maximum, and (b) one containing all larger values of particle radii. In some of the test runs, however, it was found that the interval containing the smaller radii required more halvings than the other interval, but contributed only a small fraction of the total extinction effects--thereby wasting computation time.

The effect of using just a single size interval, instead of two intervals, has been briefly explored using a special version of AGAUSX, and Deirmendjian's cloud models C.1 and C.3 at $\lambda = 0.7\mu m$. Computations were made with several different values for the convergence level (Δ). Table 10 compares some of the results found with the special version (AGAUS1OS) and the regular version. The scattering fraction computations were made at 2^0 increments in most cases shown in the table, and the column labeled "NI" explicitly shows the number of size intervals used. Also shown and labeled "REF CASE", are the results obtained with an AGAUSX run which used all 513 available values of particle radii.

The results seen in table 10 indicate that the special version (AGAUS1OS) required only one-third to one-half as much computation time to satisfy the different convergence levels as AGAUSX needed. It thus appears that the initial assumption that two intervals would be preferable to one interval may be false. However, a closer examination of the table shows that AGAUS1OS yielded substantially large scattering fractions (away from 0^0) than did AGAUSX, with the latter code's values being closer to the "REF CASE" values at all choices of Δ.

About the only conclusions which can be drawn at this point are that the NI = 1 version is by far the most efficient when only k_{ext} is of interest, and that the NI = 2 version is preferable, in spite of its slower speed, if high accuracies are needed for the scattering fractions at large scattering angles. From another vantage point, however, the discrepancies between the NI = 1 and NI = 2 scattering fractions at $\theta = 90^0$ and $\theta = 180^0$ are an insignificant fraction of the $\theta = 0$ values.

A few similar comparisons for Deirmendjian's cloud model C.3 at $\lambda = 0.7\mu m$ are given in table 11.

Comparison of Results for the Analytic Phase Functions: Two models have been chosen to compare the two analytic phase functions, Henyey-Greenstein and Goedecke-Henyey-Greenstein with the 'true' or computed phase function. These models and selected wavelengths at which comparisons were made are: simulated

TABLE 10

COMPARISON OF RESULTS PRODUCED FOR CLOUD MODEL C.1 (λ = 0.7μm)

BY SEVERAL VARIANTS OF PROGRAM AGAUSX AND DIFFERENT CONVERGENCE LEVELS (Δ)

DELTA	*	NI	NRADI	K_{ext}	CPU	Scattering Fractions		
						0°	90°	180°
	a	2	26	17.47	45.28	2.4521	5.2019E-5	7.4914E-4
0.05	b	1	9	16.70	21.06	2.2353	6.9736E-5	1.29463-3
	c	1	9	16.70	note-d	2.2353	6.9736E-5	1.2946E-3
	a	2	50	16.72	82.81	2.2404	4.8011E-5	8.3856E-4
0.01	b	1	17	16.77	38.72	2.2438	7.0311E-5	1.0222E-3
	c	1	129	16.74	note-d	2.2386	5.6969E-5	9.1422E-3
0.005	a	2	66	16.74	127.93	2.2395	5.6570E-5	8.7430E-4
	b	1	17	16.77	37.78	2.2438	7.0311E-5	1.0222E-3
0.001	a	2	130	16.73	245.13	2.2370	5.4473E-5	8.2393E-4
	b	1	33	16.76	75.71	2.2398	6.8529E-5	9.3237E-4
"Reference Case"	c	2	513	16.75	note-d	2.2411	5.5880E-5	8.8647E-4
Deirmendjian		1	440	16.73		2.2370		8.457E-4

*NOTES: (a) "Normal" AGAUSX convergence tests on aerosol volume; 2 size intervals.

(b) AGAUS10S; convergence tests on extinction coefficient; 1 size interval.

(c) AGAUS10S; convergence tests on extinction coefficient and scattered intensity at θ = 90°; number of size intervals given in column labeled "NI".

(d) 45° angular increment runs; CPU times not directly comparable to other runs made at 2° increments.

TABLE 11

COMPARISON OF AGAUSX RESULTS FOR CLOUD MODEL C.3 (λ = 0.7μm) USING ONE AND TWO SIZE INTERVALS, SEVERAL CONVERGENCE LEVELS AND CONVERGENCE TESTS ON EXTINCTION COEFFICIENT AND SCATTERING FRACTIONS AT 90°

					Scattering Fractions		
DELTA	NI	NRADI	K_{ext}	CPU[a]	0°	90°	180°
0.1	--	--	--	--	--	--	--
	1	33	3.042	34.81	5.4626E-2	2.2433E-5	2.5350E-4
0.05	--	--	--	--	--	--	--
	1	65	3.041	68.71	5.4583E-2	2.2435E-5	2.3498E-4
0.01	2	66	3.008	71.49	5.3569E-5	2.1668E-5	1.7792E-4
	1	65	3.041	72.67	5.4583D-2	2.2435E-5	2.3498E-4
0.005	--	--	--	--	--	--	--
	1	65	3.041	72.06	5.4583E-2	2.2435E-5	2.3498E-4
0.001	2	130	3.015		5.3796E-2	2.2180E-5	1.9798E-4
	1	129	3.041	16.86[b]	5.4585E-2	2.1382E-5	2.3500E-4
.0001	1	513	3.021	62.83[b]	5.3985E-2	2.0643E-5	2.0382E-4
Deirmendjian		280	3.021		5.396E-2	--	2.025E-4

NOTES: (a) CPU times in seconds, using 2° angular increments.

(b) Not comparable to other runs due to use of 45° increments.

(c) Cases for which dashes (---) appear were not run for NI=2 and convergence tests on both K_{ext} and the scattered intensity at θ = 90°.

white phosphorus[7] at 1.06 and 10.6 microns; fog model WSMRF2 at wavelengths of 2.5, 10.0 and 11.0 microns; the parameters for each of the two fog models are tabulated below.

	WSMRF2
Radius, Minimum	0.4μm
Radius, Maximum	12.0μm
Radius, Mode	4.0μm
Alpha	6.0
Gamma	1.0
Particle Density	$100.0cm^{-3}$

Values of the analytical phase functions HG and GHG, along with the computed phase functions are presented graphically in figures 1 through 5. A visual inspection of these figures shows that the GHG analytic phase function matches the computed phase function far better than the HG phase function near zero degrees, and that the GHG function apparently provides a better overall fit to the computed phase function than the HG function. Because the scales of the graphs usually do not permit sufficient resolution near 180°, the values of the computed and analytic phase functions are presented in table 12 at selected angles. Table 12 also presents the differences between the computed and analytic phase functions at the selected angles, and also the root mean square error for the points considered.

Discussion: Inspection of table 12 shows that the GHG analytic phase function is superior to the HG analytic phase function at angles near zero degrees.

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[7] A. Miller, R. C. Shirkey, E. Gemoets and G. H. Goedecke, 1978, Investigations on the Prediction of Infrared Transmission and Emission by Clear and Aerosol Laden Atmospheres, NMSU Department of Physcis, Final Report for Contract DAEA18-77-C-00003

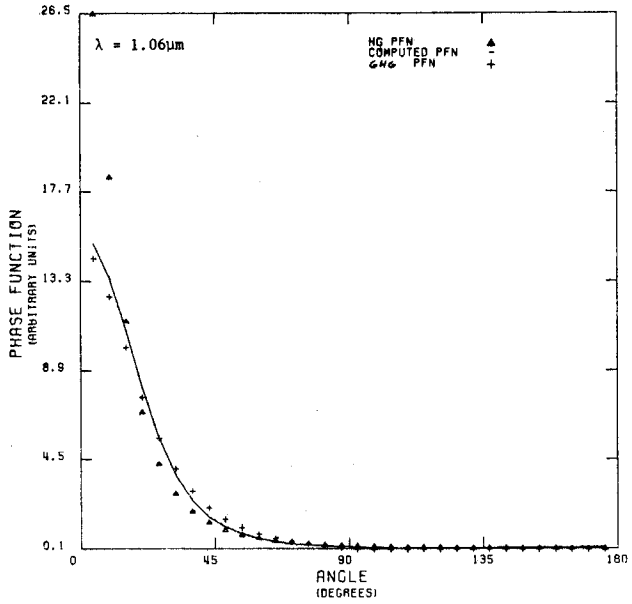

Figure 1. Comparison of analytic phase functions HG and GHG with computed phase function for simulated white phosphorous at 1.06μm.

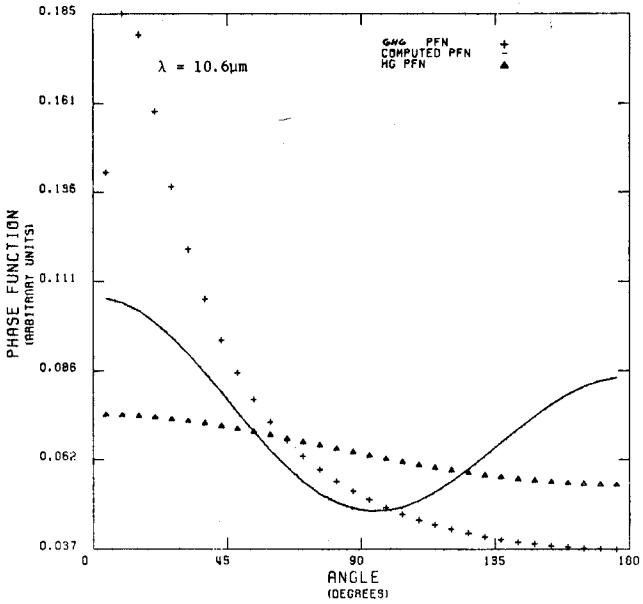

Figure 2. Comparison of analytic phase functions HG and GHG with computed phase function for simulated white phosphorous at 10.6μm.

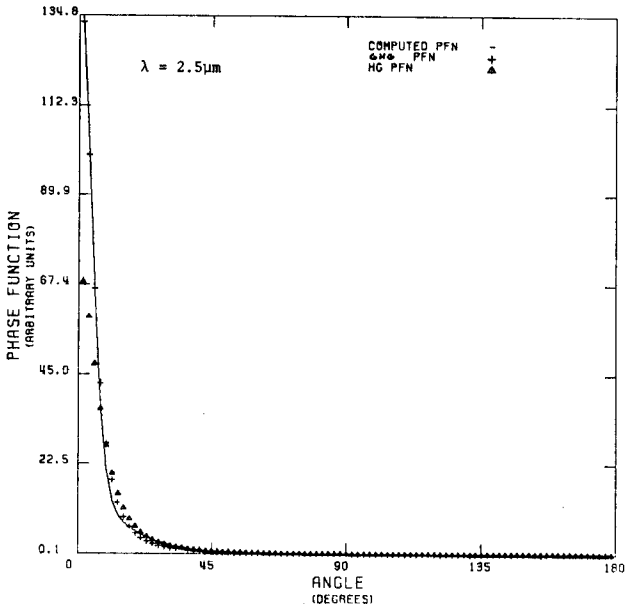

Figure 3. Comparison of analytic phase functions HG and GHG with computed phase functions for fog model WSMRF2 at 2.5μm.

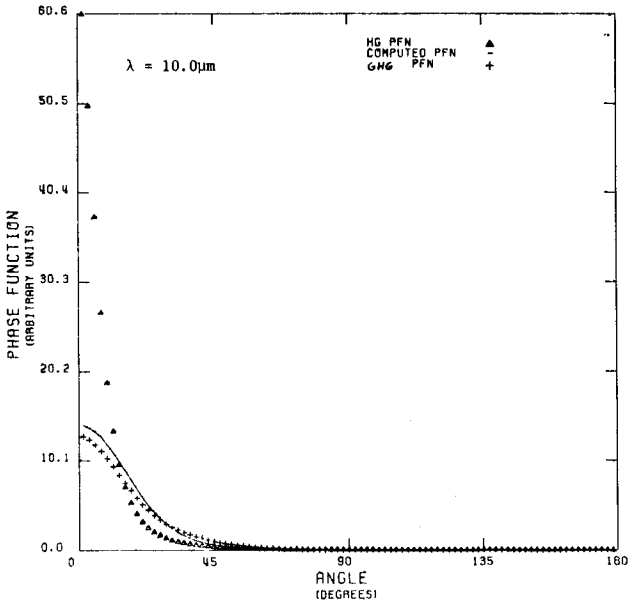

Figure 4. Comparison of analytic phase functions HG and GHG with computed phase functions for fog model WSMRF2 at 10.0μm.

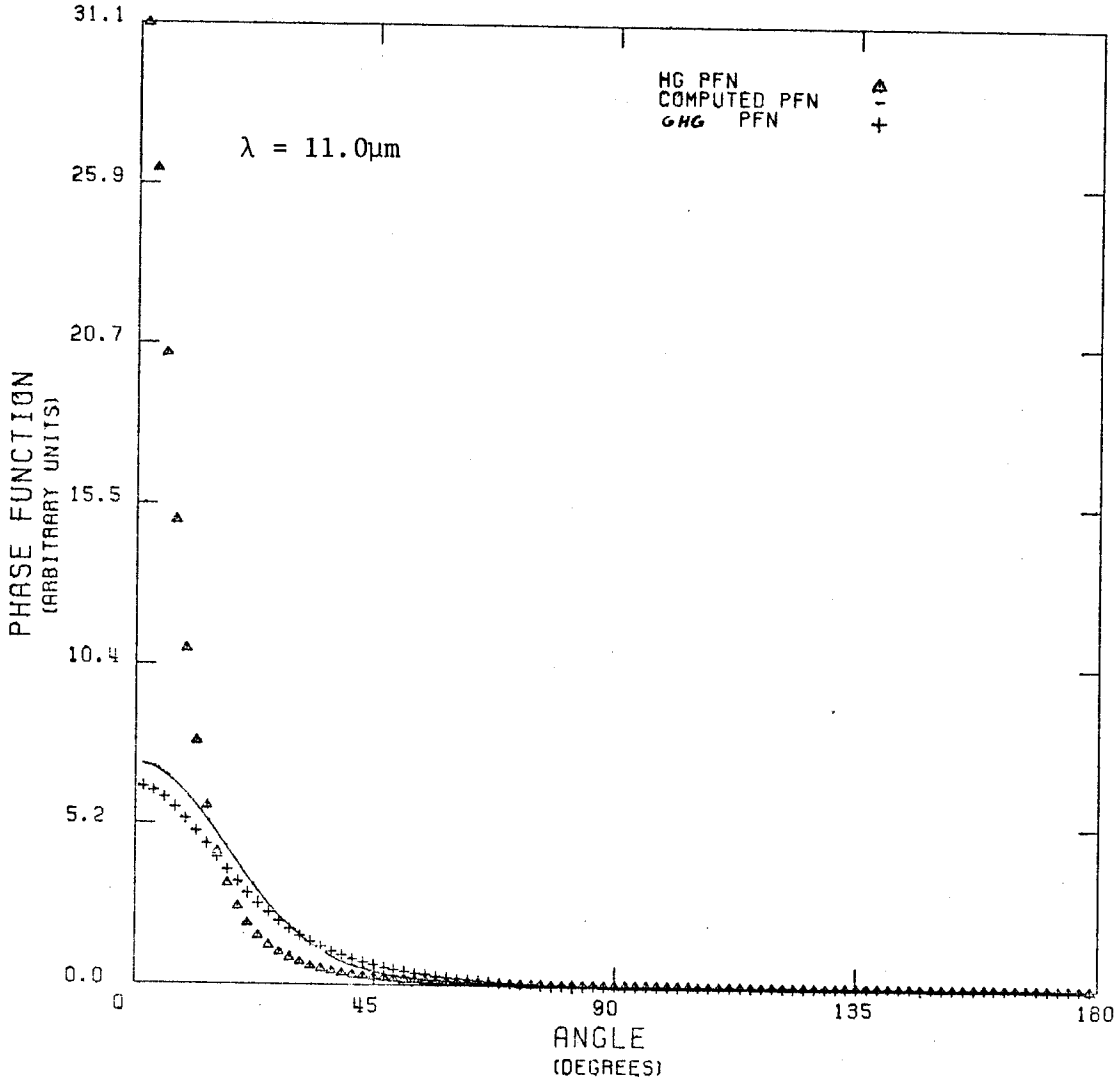

Figure 5. Comparison of analytic phase functions HG and GHG with computed phase function for fog model WSMRF2 at 11.0μm.

TABLE 12

COMPARISON OF COMPUTED AND ANALYTIC PHASE FUNCTION VALUES AT SELECTED ANGLES FOR FOG MODEL WSMRF2 AND SIMULATED WHITE PHOSPHOROUS AT VARIOUS WAVELENGTHS

Wavelength 2.5μm	Model WSMR F2 Phase Function Values*				
Angle(°)	True †	HG	HG-GG	Δ_1^+	Δ_2^+
1.51	134.80	68.17	133.20	66.63	1.60
25.08	3.59	3.56	2.56	.03	1.30
50.66	.49	.55	.43	-.06	.06
74.26	.13	.20	.18	-.07	-.05
99.84	.06	.10	.11	-.04	-.05
125.41	.09	.06	.08	.03	.02
150.98	.09	.05	.07	.04	.02
174.58	.17	.05	.07	.12	.10
178.49	.23	.05	.07	.18	.16
				22.21	.64

Wavelength 10.0μm	Model WSMR F2 Phase Function Values*				
1.51	14.12	60.63	12.86	-46.51	1.26
25.08	4.32	2.07	3.97	2.25	.35
50.66	.38	.30	.68	.08	-.30
74.26	.08	.11	.09	-.03	-.01
99.84	.03	.05	.00	-.02	.03
125.41	.02	.04	.00	-.02	.02
150.98	.02	.03	.00	-.01	.02
174.58	.02	.02	.00	.00	.02
178.49	.02	.02	.00	.00	.02
				15.52	.45

Table 12 (cont)

Wavelength 11.0μm Angle(°)	True†	Model WSMR F2 Phase Function Values* HG	HG-GG	Δ_1^+	Δ_2^+
1.51	7.14	31.08	6.39	-23.94	.75
25.08	2.61	1.28	2.34	1.33	.27
50.66	.26	.19	.45	.07	-.19
74.26	.05	.07	.07	-.02	.00
99.84	.02	.03	.01	-.01	.01
125.41	.01	.02	.01	-.01	.00
150.98	.01	.02	.01	-.01	.00
174.58	.01	.02	.01	-.01	.00
178.49	.01	.02	.01	-.01	.00
				7.99	.27

Wavelength 1.06 and 10.6μm	Model WP (1.06μm) Phase Function Values*					Model WP (10.6μm) Phase Function Values*				
4.24	15.15	26.52	14.40	-11.37	.75	.11	.07	.14	.04	-.03
26.32	5.58	4.26	5.55	1.32	.03	.10	.07	.14	.04	-.04
48.47	1.15	1.00	1.53	.15	-.38	.07	.07	.09	.00	-.02
76.16	.26	.32	.29	-.08	-.03	.05	.07	.06	-.02	-.01
98.30	.13	.18	.02	-.05	.11	.05	.06	.05	-.01	.00
126.00	.10	.11	.02	-.01	.08	.06	.06	.04	.00	.02
148.14	.12	.09	.02	.03	.10	.07	.06	.04	.01	.03
175.76	.17	.08	.02	.09	.15	.08	.05	.04	.03	.04
RMS# =				4.05	.31				.02	.03

*Rounded to two decimal points
†Computed via Mie Theory
+True minus analytic: 1 = Henyey-Greenstein; 2 = modified Henyey-Greenstein.
#RMS = Root Mean Square

However, as one approaches 180° the HG function sometimes provides a better fit to the computed phase function. Since for most of the distributions examined the backscatter is far less than the forward scattering, it becomes important to analytically fit the computed phase function more closely near the forward direction of scattering relative to the backscatter direction. Additionally since the HG analytic function fits the computed phase function best near 180° and the GHG analytic function is partially comprised of the HG function near 180°, we again find that the GHG analytic function will fit well near 180°. The root mean square error is also presented for the difference between the computed and analytic phase functions, and again indicates that the GHG analytic phase function provides a better fit. This is particularly so if the particular regime under consideration is near the incident (forward) direction.

STUDIES OF IR EXTINCTION IN HYGROSCOPIC AEROSOLS

Introduction: In a previous document[7] some results of the modeling of IR extinction in hygroscopic aerosols were reported. Since then additional computations have been made to extend the range of relative humidities beyond that used previously and to examine the effects of "hysteresis" in the condensation and evaporation of droplets formed upon hygroscopic condensation nuclei. The new calculations were carried out using the simulated white phosphorous smoke model A' defined in the report referenced above.

Computations were carried out with an early version of program AGAUS9 at wavelengths of 0.55, 1.06, and 3.6μm. Twelve values of relative humidity were used, and mass accretion coefficients were taken from Hanel[8] for conditions of

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[7] A. Miller, R. C. Shirkey, E. Gemoets and G. H. Goedecke, 1978, Investigations on the Prediction of Infrared Transmission and Emission by Clear and Aerosol Laden Atmospheres, NMSU Department of Physics, Final Report for Contract DAEA18-77-C-00003

[8] G. Hanel, 1976, "The Properties of Atmosphere Particles as Functions of the Relative Humidity at Thermodynamic Equilibrium with the Surrounding Moist Air," Advan Geophys, Editors H. E. Landsberg and J. Van Mieghem, Academic Press, New York

Results: The data generated by the new computations are presented in graphical form in figures 6 through 8. Figure 6 shows the absolute extinction coefficients as a function of relative humidity at $\lambda = 0.55\mu m$ and $\lambda = 1.06\mu m$. The arrowheads indicate the direction in which relative humidity is changing; an arrowhead tilted toward the right represents increasing relative humidity, and an arrowhead tilted toward the left represents decreasing relative humidity. Figure 6 clearly shows the "hysteresis" effect mentioned above. It will be seen that for relative humidities between about 60 and 75 percent, the value of the extinction coefficient may vary by a factor of two between conditions of rising and falling relative humidity. For both wavelengths shown, figure 6 can be interpreted as suggesting that clearing (associated with droplet evaporation) of a smoke cloud under conditions of decreasing relative humidity is slower than its formation at any given relative humidity between about 50 and 75 percent. The figure also demonstrates that the sense of changes in relative humidity may be as important as its value in modeling hygroscopic aerosols.

In figure 7 one will find graphs of the ratios of the extinction coefficients at 1.06μm and 3.56μm to those at 0.55μm as a function of relative humidity, figure 7 is subject to various interpretations. One inference is that the aerosol model used for these calculations is almost always (all relative humidities = 99 percent) more "transparent" at 3.56μm than at 0.55μm, but the same statement cannot be made at 1.06μm. This particular aerosol, while more transparent at 10.6μm than at 0.55μm for relative humidities below about 59 percent, is comparatively less transparent for larger saturation ratios. Other features discernable from figure 7 are that extinction at 1.06μm as compared to its value at 0.55μm is much less sensitive to relative humidity than it is for 3.56μm radiation. In other words, the extinction at 1.06μm can be predicted more accurately from knowledge of the extinction at 0.55μm than can be the extinction at 3.56μm when no information on relative humidity is available. One further obvious inference from figure 7 is that extinction at 1.06μm will be greater than at 0.55μm if the smoke cloud is clearing because of decreasing relative humidity.

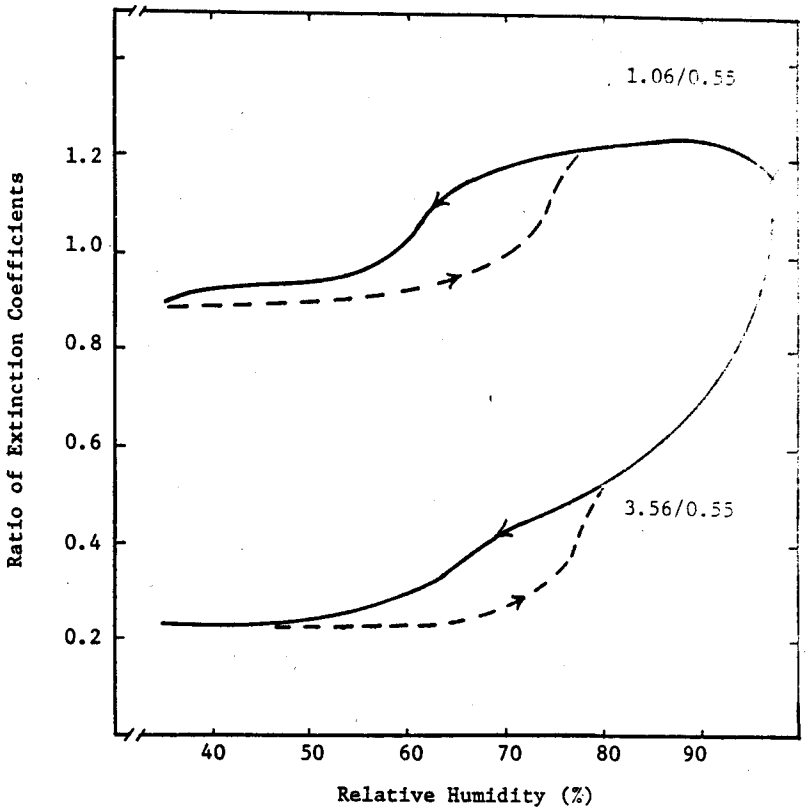


Figure 6. Computed extinction coefficients for smoke model A' as a function of relative humidity; λ is the wavelength in μm. The solid curves and broken curves represent conditions of decreasing and increasing relative humidity, respectively.

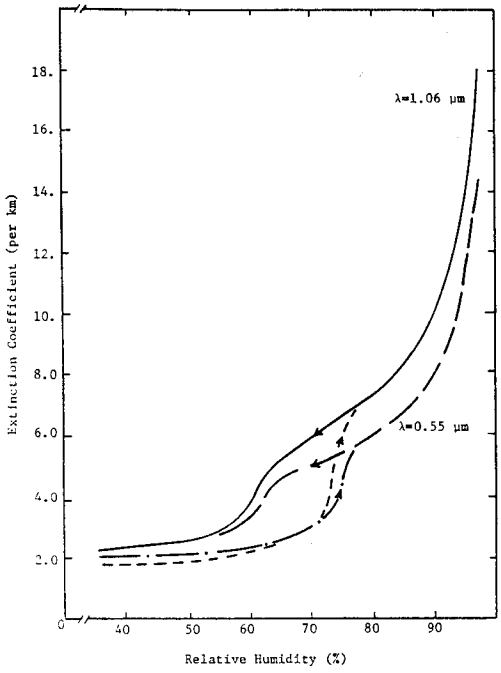


Figure 7. Ratio of Model A' extinction coefficients at λ = 1.06μm and λ = 3.56μm to values at λ = 0.55μm as a function of relative humidity. The solid curves represent increasing relative humidity, and the dashed curves represent decreasing relative humidity.

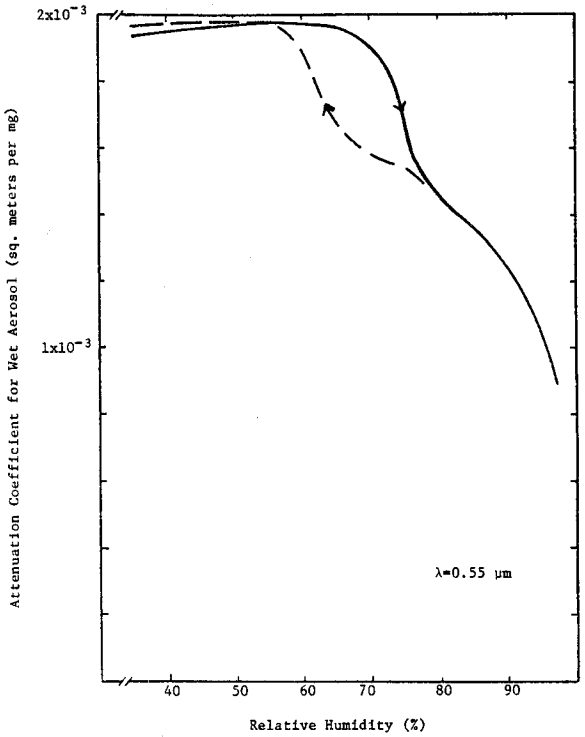


Figure 8. Attenuation coefficient per unit mass of Wet Aerosol at 0.55μm versus Relative Humidity for smoke model A'. The solid curve is for increasing relative humidity and the dashed curves represent decreasing relative humidity.

Finally, figure 8 shows the attenuation coefficient per unit mass of WET aerosol at $\lambda = 0.55\mu m$ as a function of relative humidity. If that figure is compared with figure 6, it will be seen that the attenuation per unit mass of the existing aerosol (WET → nuclei + accreted water) is much less sensitive to relative humidity than the attenuation per unit mass of dry aerosol material. It suggests that simultaneous in situ measurements of aerosol mass concentrations and extinction which preserve accreted water should yield less uncertainty or variation in extinction with changes in relative humidity than measurements made on dry aerosol materials alone.

Discussion: The results described above can, of course, be applied in detail only to the aerosol model used in generating them and at the specific wavelengths used. They do suggest, however, that extinction can, under some situations at least, vary by nearly a factor of two at a given relative humidity between conditions or rising and falling relative humidity, and that the relationship between extinction at two different wavelengths may also be dependent on the direction of changes in relative humidity. Consequently, it would seem that persons involved in both field measurements and numerical modeling should pay considerable attention to meteorological conditions, in particular when the relative humidity is rising or falling.

FURTHER DESCRIPTION OF THE "HALVING" METHODS OF AGAUSX

Basic Concept. A general idea of how program AGAUSX operates can be obtained by considering a numerical method for determining the area under a curve g(R) versus R such as that sketched in figure 9. The objective is to evaluate numerically an integral

$$G = \int_{R=o}^{R=\infty} g(R)\, dR \qquad (61)$$

to some desired degree of accuracy using the smallest number of values of R for the numerical calculations. The procedure adopted in AGAUSX is as follows (reference to figure 9 may be helpful):

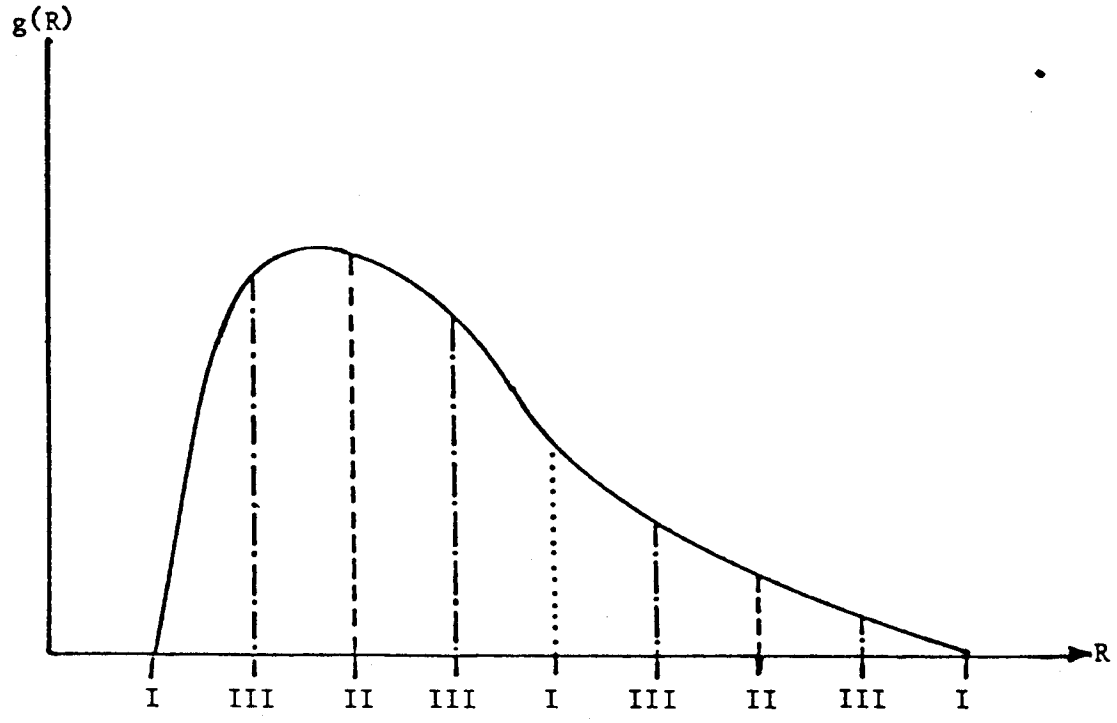


Figure 9. Sketch of how values of particle radii are selected in the halving procedure of AGAUSX.

(1) An initial estimate G_1 of the value of the integral is made using three values of R labeled by Roman numeral I and the "trapezoidal rule".

(2) A second estimate G_2 is then made using increments ΔR which are half as large as those used in getting G_1. In getting G_2, the two additional R-values labeled II are utilized.

(3) The values of G_2 and G_1 are compared to each other by calculating a quantity

$$\delta = \frac{|G_2 - G_1|}{|G_2|} \tag{62}$$

and comparing it to a pre-set quantity Δ.

If $\delta < \Delta$, then it is assumed that G_2 is a "sufficiently" accurate representation of G, and the computations are terminated. If on the other hand, $\delta > \Delta$, one proceeds.

(4) A third estimate G_3 of G is then made by again cutting the increments ΔR to half its previous value. This results in the addition of computations at the four new R-values labeled III in figure 9. A new value of δ is then calculated from

$$\delta = \frac{|G_3 - G_2|}{G_3} , \tag{63}$$

and δ is again compared to Δ. If δ is still greater than Δ, the spacing between R-values is cut in half once more, and the "estimation-comparison" process is repeated until either (a) $\delta < \Delta$, or (b) some maximum number of R-values has been reached.

In AGAUSX, the quantity used in the testing process is the total volume of the aerosol particles, namely,

$$V = \int \frac{4}{3} \pi R^3 \, f(R) dR, \tag{64}$$

in which f(R)dR is the relative number of aerosol particles whose radii lie between R and R+dR.

Extensions to the Basic Concept: It may happen that the function g(R) illustrated in figure 6 will have a form which is much "smoother" over some range of R-values than over other ranges. Strict application of the halving procedure to such a situation could easily lead to the use of many more R-values in one of those ranges than are really needed because of behavior of g(R) in other R-ranges. Such a situation seems especially likely with asymmetric size-distributions. One way of attempting to avoid unneeded computations in various R-ranges is to split the regions used in halving loops into several distinctive "intervals"--R_A to R_B, R_B to R_C, R_C to R_D, and to do the halving operations and convergence tests separately for each "interval." AGAUSX has been coded to permit separate halving computations and convergence testing for up to eight "intervals" of that type. In fact, the present coding uses two radius "intervals" (ranges) for those distributions f(R) known to show a single maximum, four "intervals" for bi-modal distribution models, and just one interval for other models.

DETAILED DESCRIPTION OF PROGRAM AGAUSX

Program AGAUSX is designed to calculate various light-scattering quantities such as phase functions (Mie theory), scattering fractions (ACT), extinction cross-section, attenuation coefficient, etc., for diverse natural and artifically created polydisperse atmospheric aerosols. The program consists of subroutines ANGLE, GUSET, AGXPT1, AGXPT2, AGXPT3, AGXPRT, MIEGS, GAUS, VERFY, WATER, GPHASX, GUSSTX, and PRINTX. The organization and operation of these subroutines is controlled by the MAIN program AGAUSX. Additionally program AGAUSX will produce an analytic (GHG) phase function if the user desires.

MAIN PROGRAM AGAUSX

The first input card contains the parameters NWAVE, NINDX, IDSTP, NRADI, IT, IANG, NCRDS, ITOT, NUNIT, MQRTE, and IAPX. These parameters will be explained in detail subsequently. The various modes of operation of AGAUSX that are possible, are controlled by some of these parameters. If IANG = 0, the subroutine GUSET is called to choose 'IT' scattering angles between 0^0 and 180^0 for use in numerical integrations using Gauss-Legendre quadrature. GUSET returns two arrays of numbers to MAIN. The array C(I) corresponds to the cosine of scattering angles and the array H(I) corresponds to the quadrature weights.

If IANG = 1 or 2, all the calculations of the previous paragraph are skipped. Instead subroutine ANGLE is called and returns arrays C(I) and H(I) to MAIN. For IANG = 1, H(I) corresponds to 'IT' equally spaced angles between 0^0 and 180^0, and C(I) corresponds to the cosine of these angles. If IANG = 2, 'IT' user supplied angles are read in, again with H(I) corresponding to 'IT' angles and C(I) their cosines.

If IAPX is greater than zero AGAUSX will operate in a special 'approximation' mode. That is AGAUSX will construct the GHG analytic phase function at IAPX Gauss-Legendre angles. When approximate, quick phase functions are desired, this mode should be used.

Next, subroutine AGXPT1 is called. One or more input parameters are read at this point depending on the value of IDSTP, which indicates the type of distribution to be used. AGXPT1 calculates and returns two arrays R(I) and F(I) which describe the normalized size distribution, and VOL, the average 'dry' volume per particle. The array R(I) contains values of 'NRADI' particle radii, and the array F(I) contains values of the distribution for the corresponding R(I). For IDSTP = 3, 7, 8, 9, 10, 11, or 12 AGXPT1 also returns DENS, the particle number density (per cm^3). For other distribution types that do not have predetermined density values, the user supplied density, DENSH, is less than 10^{-4}; in this case the particle number density will be calculated from mass densities and mass concentrations.

The parameters WAVE, DWAVE, RELHUM, DENSH, TEMP and DELTA are read next. The next do-loop indexed by NWAVE allows computations at several wavelengths during a single run. An additional looping option is available by assigning DWAVE any value less than 10^{-4}; the same do-loop is used to handle several values or relative humidity (RELHUM) in a run.

A switch parameter LLLL is assigned a value 0 or 1, in a manner dependent upon the value of IDSTP and DENSH. That is if the chosen distribution has fixed parameters and/or if number densities are to be calculated later from the average particle volume, mass density and mass concentration, then LLLL = 1.

In subroutine AGXPT2 optical and physical data (index of refraction and mass density) for the aerosol material are read. For the user's convenience, subroutine WATER has been added to provide the relevant data for water limited to the range 0.2 to 200 micrometers. If RELHUM and the growth factor (EMUA) are non-zero, AGXPT2 takes into account the particle growth and the change in density and indices of refraction of the aerosol material due to the absorption of water.

In AGXPT2, subroutine MIEGX is called for each 'adjusted' radius. MIEGX returns to AGXPT2 the values of extinction, scattering and backscattering

efficiency factors, and the average intensity factors $(I_1 + I_2)/2$ for the 'IT' scattering angles chosen earlier. These scattering functions are weighted and integrated over the size distribution.

If the aerosol is a mixture of components having different physical and/or optical properties, the above calculation is repeated for each component and various functions are summed over NINDX (the number of components). In the end AGXPT2 returns to MAIN, for each wavelength, the average (sum/total particle number density) extinction, scattering and back-scattering cross-sections (CTSUM, CSSUM, CRSUM), the average intensities (P(J)), and the total mass concentration (TMASS, in gm/cc, which includes the mass of any liquid water absorbed by hygroscopic aerosols).

The next subroutine is called AGXPT3. AGXPT3 uses the numbers received from AGXPT2 and returns to MAIN the total extinction, scattering, and back-scattering coefficients, scattering fractions and phase functions. AGXPT3 also calculates the albedo for single scattering "ALBDO" = $\tilde{\omega}_o = C_{sca}/C_{ext}$ and prints out all the single wavelength results. Later in AGXPT3, If IANG = 0, subroutine GAUS is called. Using the quadrature weights H(I) calculated earlier and calculating the Legendre polynomials PL(,), GAUS generates the Legendre expansion coefficients $\tilde{\omega}_\ell$ for the phase functions, and places them in array OL(I). The $\tilde{\omega}_\ell$'s are then used to reconstruct phase functions, PC(I): GAUSS computes the root mean square deviation between the original phase functions and the reconstructed phase functions. If IANG = 1, the above calculation is skipped.

If NWAVE > 1, all the calculations of AGXPT2 and AGXPT3 are repeated (NWAVE-1) additional times. In MAIN, various scattering functions are summed and divided by NWAVE, and subroutine AGXPRT is called to print out all the averaged results. AGXPRT also calls GAUS once more (if IANG = 0) to generate the coefficients $\tilde{\omega}_\ell$ for the averaged phase functions.

If IAPX is greater than zero, subroutine GPHASX is called to construct an analytic phase function, hereafter referred to as the GHG phase function. This requires the additional subroutines, GPHASX, GUSSTX, and PRINTX. This routine will construct the GHG analytic phase function at IAPX Gauss-Legendre

angles, and the subsequent Legendre coefficients may be written/punched on a unit specified by NUNIT if the user so desires.

Explanation of Symbols used in AGAUSX (MAIN)

SYMBOL	Explanation or Definition
ALBDO	single scattering albedo.
AMAX	the largest Mie size found in the aerosol distribution.
C( )	array holding cosines.
CATTN	the average (sum/NWAVE) attenuation coefficient in square meters per milligram of aerosol material.
CRSUM	the back-scattering cross-section in square micrometers for each wavelength and integrated over size distribution. AGXPT3 returns !coefficients!.
CSSUM	the scattering cross-section in square micrometers for each wavelength and integrated over size distribution. AGXPT3 returns 'coefficients'.
CTSUM	the extinction cross-section in square micrometers for each wavelength and integrated over size distribution. AGXPT3 returns 'coefficients'.
DELTA	convergence criterion.
DENS	the particle number density (number per cubic centimeter). The value of DENS may be supplied by the user as an input parameter, DENSH. However, it will be ignored when IDSTP = 0 or greater than 6, because these distribution types carry predetermined values of DENS. In the case of IDSTP = 1, 2, 4, 5, the user supplied value of number density

will be ignored only if it less than 10^{-4}. In such cases DENS is calculated from mass density and concentration and average volume per particle, and is represented by DENSC.

DENSH — the user-supplied particle number density; units are particles per cubic centimeter. See discussion of DENS (above).

DRYVOL — the average volume per particle of dry aerosol in cubic micrometers.

DWAVE — the wavelength increment in micrometers, or relative humidity looping indicator.

ELWC — the liquid water content in gm/cm^3 (used only for cases IDSTP = 6 and 12).

EMM — the refractive index of the surrounding medium.

ENWAV — DFLOAT (NWAVE).

FSUM — the numerical result for the integral over the size distribution function with respect to radius; it is used to normalize the distribution function to one (equivalent) particle per cubic centimeter.

GNU — wave number in cm^{-1}.

H( ) — array containing angles.

IANG — = 0, for the computation of phase functions at 'IT' Gauss-Legendre quadrature angles.

IANG = 1, for computation of phase functions and scattering fractions at 'IT' equally spaced angles between 0^0 and 180^0 . = 2, for computation of phase functions and scattering fractions at 'IT' user supplied angles.

IDSTP identified the type of aerosol size distribution to be used. It can only take values between 0 and 12. See AGXPT1 for more details.

IAPX the order of Legendre expression for the analytic, GHG, phase function expansion when IAPX is greater than zero.

IDBLE single or double precision mode industor.

IT the order of Legendre expansion for phase functions when IANG = 0, or the number of equally spaced angles between 0^0 and 180^0 when IANG = 1, or the number of user supplied angles if IANG = 2.

ITOT works in conjunction with NCRDS and NWAVE to write/punch either individual wavelength values of the phase function, (Legendre coefficients and/or scattering fractions) or averaged wavelength values or both on NUNIT: ITOT = 1 for individual wavelengths; ITOT = 2 for averaged wavelengths, ITOT = 3 for both.

KBAKT the average (sum/NWAVE) back-scattering coefficient per km, integrated over the size distribution.

KEXTT the average (sum/NWAVE) extinction coefficient per km, integrated over the size distribution.

KSCAT the average (sum/NWAVE) scattering coefficient per km, integrated over the size distribution.

LLLL — a switching parameter used to control whether or not particle number density is to be calculated from DRYVOL and mass concentration.

LMAX — = 3*IFIX (AMAX). Integer estimate of the optimal order for Gauss-Legendre quadrature; used only for diagnostic message print.

MQRTE — = 12345, will cause subroutine AGXPT2 to print efficiency factors QT, QS, and QR, and the normalized distribution function for every value of radius used.

NCRDS — = 1 for write/punch only Legendre coefficients on NUNIT: = 2 write only phase functions and scattering fractions on NUNIT: = 3 write/punch both on NUNIT.

NINDX — the number of aerosol components which will have different optical constants, mass density or mass concentration.

NRADI — the number of values of particle radius to be used in the calculations. (In effect, points on the radius versus size distribution function plot).

NUNIT — defines the device on which output data may be stored or punched; may be used to place nominal card output into data files, on tape, etc. The default value (NUNIT = 0) is 4.

NWAVE — the number of wavelengths or relative humidity values to be treated in a given run. DWAVE has to be less than 10^{-4} for the latter.

OL(I) — the average Legendre expansion coefficients. OLT(I)/ENWAVE.

OLT(I) the total Legendre expansion coefficients (summed over all values of !WAVE!).

OUT( ) an array used for storing some of the numbers to be printed later.

PL(I,J) the Legendre polynomials of order (I-1) and argument C(J). C(I) are cosines of the scattering angles.

PSUM(I) the average phase functions integrated over the size distribution.

PSUMT(I) the total phase functions integrated over size distribution and summed over wavelength.

QATTEN the attenuation coefficient in square meters per milligram of aerosol material for each wavelength.

R(NRADI) the radius of the largest particle encountered.

RELHUM the relative humidity in percent.

SCAT(I) the scattering fractions as defined in ACT for each wavelength. !IT! elements in the array.

SCATT(I) the average (sum/NWAVE) scattering fractions (ACT).

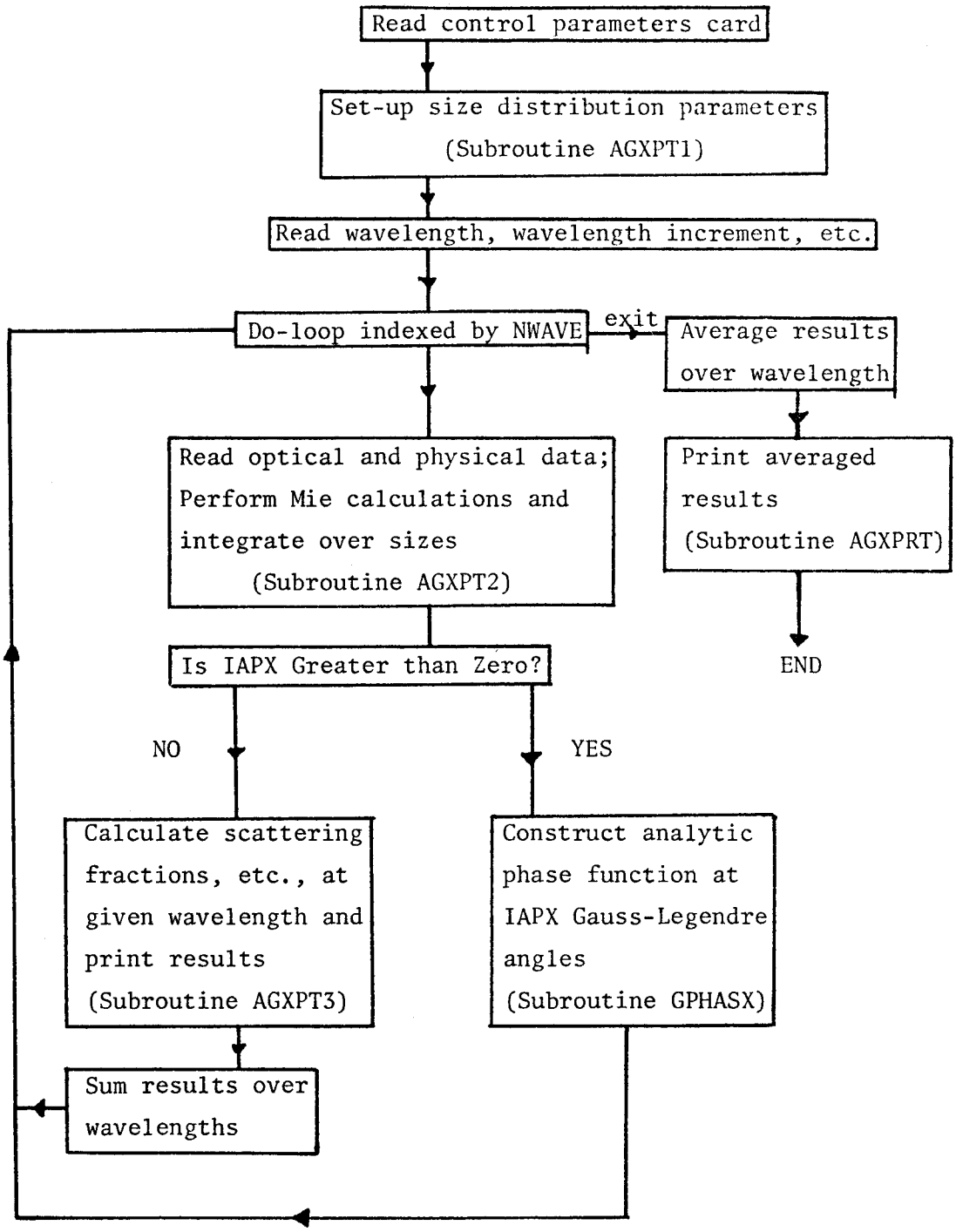
TEMP the temperature of the atmosphere in degrees C.

TMASS the total mass of aerosol in gm/cm^3 in the atmosphere.

VOL the average volume per particle in cubic micrometers.

WAVE the first wavelength, in micrometers, at which calculations are to be done.

AGAUSX (MAIN PROGRAM) - SIMPLIFIED FLOWCHART



SUBROUTINE AGXPT1

Readers of the following descriptions of the mathematical procedures should bear in mind that the general AGAUS single scattering code computes a number of quantities associated with the Mie theory of the interaction of a single spherical scatter and then averages those quantities using the aerosol size distribution function, f(r), as a weighting factor. The following definitions may also be helpful.

The terms "component" or "aerosol component" apply to cases in which the overall aerosol may be a mixture of different materials whose optical properties, mass density, growth factors, or mass concentrations are not identical. The number of "components" to be used in a run is specified by input parameter NINDX. An example of a multi-component aerosol might be one which is a mixture of hydroscopic and nonhydroscopic particles.

The terms "size interval" and/or "original interval" refer to subdivisions of the total range of aerosol radii ($R_{minimum}$ = RLO to $R_{maximum}$ = RHI) within which the halving and convergence testing procedures are applied independently.

Most averages that must be done are of the form

$$G \equiv \int_{RLO}^{RHI} dr\ f(r)G(r)/FSUM, \qquad (67)$$

where G(r) is some Mie theory quantity for a particle of radius r, and a given optical type (refractive index m = m-ik), and

$$FSUM = \int_{RLO}^{RHI} dr\ f(r).$$

The size distributions f(r), RLO $\leq$ r $\leq$ RHI, may be given in analytic form, or numerically on a set {R(J)} of values of r. They may or may not be normalized to unity (FSUM may equal 1.0, or not). The relevant Mie theory quantities include $C_{ext}(r)$, $C_{sca}(r)$, $p(r,\mu)$ for each Gauss-Legendre μ, etc. Other averages that must be done have somewhat different forms, e.g.,

$$\tilde{\omega}_n = \frac{1}{C_{ext}} \int dr\ f(r)\tilde{\omega}_n(r)C_{ext}(r)/FSUM, \tag{68}$$

for the coefficients $\tilde{\omega}_n$ of the phase function expression. $p(\mu) = \sum_{n=o}^{\infty} \tilde{\omega}_n P_n(\mu)$, in terms of the coefficients $\tilde{\omega}_n(r)$ of the phase function $p(r,\mu) = \sum_{n=o}^{\infty} \tilde{\omega}_n(r) P_n(\mu)$.

The above integrals over r must be done numerically. In order to minimize computation time, the number of points in the numerical integration should be chosen as small as possible, consistent with adequate accuracy. Each value of r that is used requires the full Mie calculation for the quantities $C_{ext}(r)$, $C_{sca}(r)$, $p(r,\mu)$ for each μ, etc., these calculations absorb a large part of the total computation time. It has been found in this work that, instead of fixing the number of values of r to be 500, adequate accuracy results, in many cases, for as few as 50 to 100 values of r; this reduction allows a reduction in total computation time by roughly a factor of 4 to 8.

The numerical integration method which was developed makes use of successive halving of intervals until a preset convergence criterion is met. This halving method allows an initial set of unequal intervals to be chosen. For example, suppose that the distribution function f(r) is sharply peaked around some value of r, and also has a long tail, as in figure 10. Then it makes

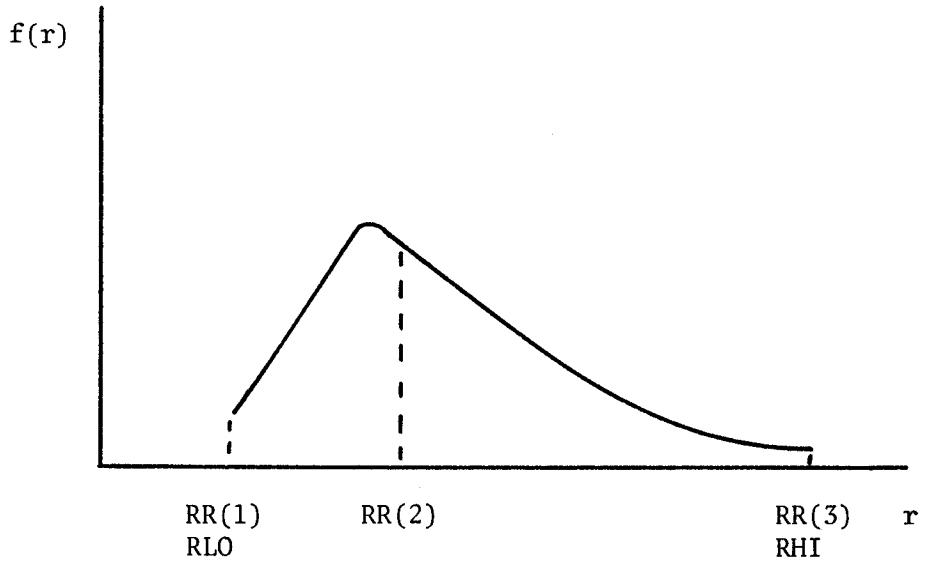


FIGURE 10: Sketch of a hypothetical size-distribution.

The logical flow through the halving integration of AGXPT1 is as follows:

(1) Given RLO, RHI and f(r), RLO $\leq$ r $\leq$ RHI, in analytic form; or f(r) numerically on the equally spaced set r = R(J), J = 1, NRADI.

(2) For the given f(r), RLO, RHI, choose the number and size of the original intervals. That is, choos RR(I), I = 1, NLAST = 2**MIN + 1, with RR(1) = RLO, RR(NLAST)= RHI. Note that NI = number of initial intervals = 2**MIN = 1,2,4,8,16,... . Then set NHALV = number of halvings in each interval = MAX-MIN, and NK = maximum number of points in each interval = 2**NHALV.

(3) The maximum number of points allowed in NMAX = 1+2**MAX. In this work, MAX = 9 was used, so NMAX = 513. Calculate R(KK), F(KK) = f(R(KK)), KK = 1, NMAX, on all the points R(KK) which might be used if

the halving goes all the way to NMAX points. For f(r) given numerically, this is done by linear interpolation.

(4) Calculate $C_{ext}(I) = \int_{RR(I)}^{RR(I+1)} dr\ f(r)C_{ext}(r)$ in each interval number I, I = 1, NI, by halving of that interval and the trapezoidal rule, until the convergence criterion is met in that interval, or until the halving has progressed all the way to NK points, the maximum number allowed in any interval. At the same time, calculate $FSUMG(I) = \int_{RR(I)}^{RR(I+1)} dr\ f(r)$, and all other needed averages $G(I) = \int_{RR(I)}^{RR(I+1)} dr\ f(r)G(r)$, on the same set of points used for $C_{ext}(I)$. (This means that the convergence criterion is applied only to $C_{ext}(I)$). Then $C_{ext} = \sum_{I=1}^{NI} C_{ext}(I)$, $FSUM = \sum_{I=1}^{NI} FSUM(I)$, etc.; then $C_{ext} = C_{ext}/FSUMG$, $G = G/FSUMG$. The last step is equivalent to making $\int_{RLO}^{RHI} dr\ f(r) = 1.0$.

sense to choose unequal initial intervals as shown. The numerical integration then proceeds by halving each of the original intervals, until the convergence criterion is met. The convergence criterion that was used is the requirement that $|G^{(n+1)} - G^{(n)}|/|G^{(n)}| < \Delta$, where Δ is some small preset number. Here $G^{(n)}$ is the value of the integral G after the nth halving, separately in each initial interval. The trapezoidal rule was used throughout. The value of the integrand at any given point r is calculated just once; it does not have to be recalculated on that point after halving.

Description of Types of Distributions

IDSTP	DESCRIPTION
0	This is an arbitrary user-supplied distribution. 'NRADI' + 1 cards will be read; the first card contains RLO and DELLR (μm). The rest of the cards carry the values of F(J) and must be in order of increasing radius value.
1	This is the zero-order log-normal distribution: the distribution function is given by

$$F(R) = \frac{1}{\sqrt{2\pi}\ \ell og_e(\sigma)R} \exp\{ - \frac{1}{2} [\frac{\ell og_e(R/\bar{R})}{\ell og_e(\sigma)}]^2\} .$$

R ≡ RBAR; σ ≡ SIGMA, is the standard deviation. This distribution type requires one input data card to read in the values of $\bar{R}$, σ, RLO and RHI.

2 This is called the double exponential distribution and its distribution function is given by $F(R) = QA \exp(-AR) + (1-Q)B \exp(-BR)$. $Q \equiv$ CUE. This distribution type requires one input data card to read in the values of RLO, RHI, Q, A, and B. Q is dimensionless while A and B have units of μm^{-1}.

3 This model (Deirmendjian's "Model C") does not require any input data card. It carries fixed value of DENS, RLO, and DELRD. RHI is determined by the input parameter NRADI.

$$F(R) = 450.2 \qquad R \leq .08$$
$$= 2.251*DELRD*R^{-4} \qquad R > .08$$

4 The distribution function of this model (Junge distribution) is given by $F(R) = QR^{-A}$, $Q \equiv$ CUE. This distribution type requires one input data card to read in RLO, RHI, A, A.

5 The distribution function for the Modified Gamma/Generalized Khirgian-Mazin distribution is

$$F(R) = R^{\alpha} \exp\left[-\left(\frac{R}{R_c}\right)^{\gamma} \cdot \frac{\alpha}{\gamma}\right], \quad \alpha \equiv \text{ALF}, \ \gamma \equiv \text{GAM}, \text{ and}$$

$R_c \equiv$ RC. One input card is needed to read in RLO, RHI, RC, ALF, GAM, and ELWC. ELWC is not needed for type 5 distribution and therefore can be left blank.

6 The size distribution model (NMSU Fog or Cloud Model) is very similar to type 5, except that the user must supply one additional input parameter--namely, the liquid water content (ELWC) in gm/cc. This model can be used for treating situations involving liquid water aerosols like clouds or fogs. For type 6 runs one does not need to read in the values of EMA, CAYA, RHOA, CONC.

7 This distribution is essentially same as Junge's distribution (type 4) except that it has fixed parameters. One input card is needed to read in VIS (visibility in km); VIS is used in calculating DENS.

8 This is a fixed parameter Continental Bi-modal Model. It does not require an input data card.

9 This is a fixed parameter Maritime Bi-modal Model. It does not require an input data card.

10 This is a fixed parameter Urban Bi-modal Model. It does not require an input data card.

11 This is a user-supplied Bi-modal Model. This requires one input card to read in FOA, FOC, SGA, SGC, RBARA, RBARC. Types 8, 9, 10, and 11 use the sum of two log-normal distributions:

$$F(R) = \sum_{i=1}^{2} \frac{N_i}{\sqrt{2\pi}\ \log_e(\sigma_i)R} \exp\left[-\frac{1}{2}\frac{\log_e(R/\bar{R}_i)}{\log_e(\sigma_i)}\right]^2$$

$N_1 \equiv$ FOA, $R_1 \equiv$ RBARA, $\sigma_1 \equiv$ SGA with similar meaning for N_2, R_2, and σ_2. Note that in Type 8, 9, 10 the values of SGA and SGC are $\log_e(\sigma)$.

12 This model (Marshall-Palmer Rain Model) is a simple exponential model which assumes an empirical relationship between rain rate and droplet size distribution parameters:

$$F(D) = N_o \exp(-\Lambda D).$$

$N_o = 0.08\ cm^{-4}$, and $\Lambda = 41(RN)^{-0.21}$ in which RN = RAIN is the rain rate in mm/hour. Diameter D is in cm. The corresponding size distribution function of radius R is given by

$$F(R) = 2N_o \exp(-2\Lambda R).$$

This distribution requires one input data card to read in RAIN. The values of RLO and RHI are fixed at 0 and 0.5 cm respectively. Due to the limitations on the range of Mie-sizes (subroutine MIEGX) type 12 usage is limited to wavelengths of the order of 1 mm or larger. Since subroutine WATER does not contain optical data for wavelengths longer than 0.2 mm, type 12 runs require the user to supply the values of EMA, CAYA, and RHOA as if rain were a non-aqueous aerosol.

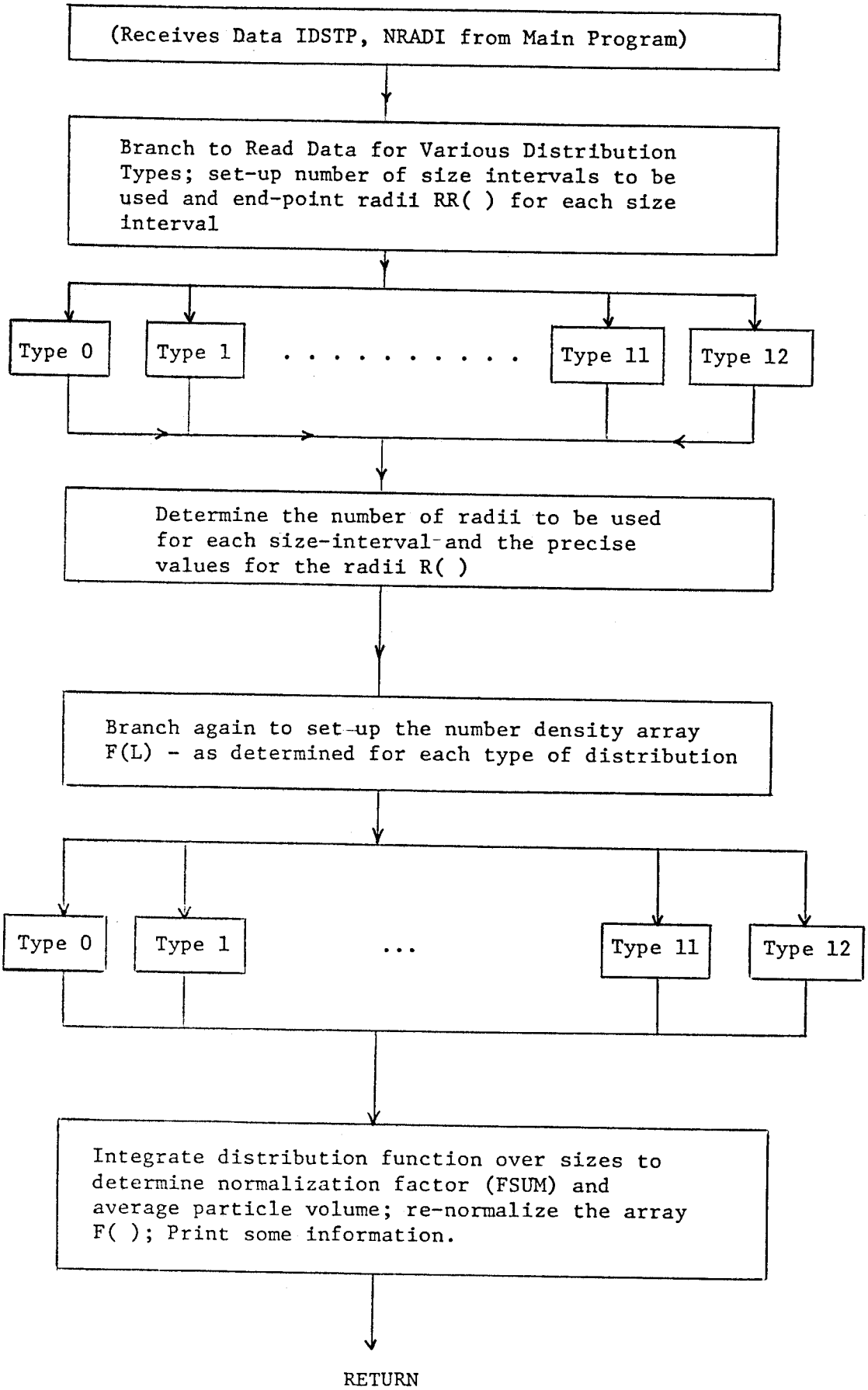
SYMBOL	Explanation or Definition
A	parameter in several distribution types.
ALF	parameter in modified gamma distribution.
AVOL	the average volume per particle in cubic microns obtained via analytical integration over the limits RLO = 0 and RHI = ∞. That has only been done for IDSTP = 5,6,8,9,10,11,12.
DENA	temporary storage.
DENC	temporary storage.
DENS	the particle number density in cm^{-3}.
DELR	increment of radius for arbitrary distribution.
DELRD	= (RHI-RLO)/RADS; increment between successive values of R.
DELLR	increment in radius for the case IDSTP = 0.

SYMBOL	Explanation or Definition
DR ( )	initial size ingerval I = 1, NI.
EM	real part of refractive index of actual aerosol particle.
EMM	refractive index of medium in which scattering particles are deployed.
F(J)	the array containing 'NRADI' values of the size distribution function. See the description of AGXPT1 for more details.
FKK	value of distribution function at radius R(KK)/
FSUM	the numerical integral over the size distribution function with respect to radius between the limits RHI and RLO; used to normalize the distribution function.
GAM	parameter in modified gamma distribution.
GNUM	temporary storage.
GNUMA	temporary storage.
GNUMC	temporary storage.
IDSTP	identifies the type of aerosol size distribution to be used.
IW	switch for "all water" mode.
NCRDS	not used in this subroutine.
NHALV	maximum number of interval halvings allowed for each initial interval.
NI	number of initial intervals for halving integration.
NKG	maximum number of points which may be used in each initial interval.
NLAST	number of radii, RR(I), defining the NI basic size intervals.
NMAX	maximum number of points which may be used in halving method.

*The pre-coded (IDSTP = 8.9,10) values of SGA and SGC are the natural logrithms of the standard deviations.

SYMBOL	Explanation or Definition
NRADI	the number of radius values to be used in describing the size distribution function for type zero and 3 only.
RAIN	parameter in Marshall-Palmer rain model.
RBAR	mean radius in log-normal distribution.
RBARA	mean radius of "accumulation" mode for bimodal distribution.
RBARC	mean radius of "coarse" mode for bimodal distributions.
RC	mode radius in modified gamma distribution.
RHI	maximum particle radius for any size distribution (μm).
R(J)	the array containing 'NRADI' values of radius (particle size) in micrometers.
RLO	minimum particle radius for any size distribution (μm).
RR(I)	lower radius of Ith initial interval: RR(1) = RLO, RR(NLAST) = RHI.
SGA	standard deviation* for user supplied bi-modal log normal distribution.
SGC	standard deviation* for user supplied bi-modal log normal distribution.
SIGMA	standard deviation in log-normal distribution: used later as ln (SIGMA).
VIS	visibility in km.
VOL	the average 'dry' volume per particle (in μm^3) calculated numerically.
VOLA	particle volume.
VOLC	particle volume.

Subroutine AGXPT1 - Simplified Flow Chart



SUBROUTINE AGXPT2

Subroutine AGXPT2 deals with the most important computational aspects of AGAUSX. If RELHUM and the growth factor (EMUA) are non-zero, AGXPT2 makes adjustments in particle radii, density and refractive index of aerosol material to account for the absorption of water by aerosol particles. These adjustments are made through the following equations:

Radius: RT = AC*R(L) - BC/AC,

Index of Refraction:

i) Real part: EM = EMW + (EMA-EMW)/A,

ii) Imaginary part: part CAY = CAYW + (CAYA - CAYW)/A

Density: RHO = RHOW + (RHOA - RHOW)/A,

All the symbols used above are explained in detail below.

Next, subroutine MIEGX is called to compute single particle scattering functions QR, QS, QT, and P(J) for each adjusted radius. These scattering functions are weighted and integrated over the size distribution by the trapezoidal method. The convergence of integration for volume and the extinction cross-section is checked, and warnings are printed if the final one or two contributions exceed 5 percent of the previous total values. If there is more than one component (NINDX>1) in the aerosol with different refractive index and density, the above calculation is carried out NINDX times, and results are summed and divided by the total particle number density. In the end, the attenuation coefficients in square meters per milligram of 'wet' aerosol material are calculated. The same value of extinction coefficient is used for calculating both attenuation coefficients.

If IAPX is greater than zero, only the first three coefficients of the Legendre expansion ($\tilde{\omega}_0$, $\tilde{\omega}_1$, $\tilde{\omega}_2$) are calculated and stored in array OL( ). This is for subsequent construction of the GHG analytic phase function.

SYMBOL	Definition
A	= 1 + (RHOA/RHOW) * EMUA * CH; used in making adjustments due to water absorption by aerosol.
AC	= $A^{1/3}$.
ALBDO	single scattering albedo.
ALPHA	= 2*PI*EMM*RT/WAVE. Mie size parameter for adjusted radii.
ALPHAD	temporary storage for ALPHA.
BC	= BHT*CH; used in making adjustments in size growth.
BH	= $1.056*10^{-3}$.
BHT	= BHI(298/TEMK).
CATTN	the total attenuation coefficient in square meters per milligram of 'dry' aerosol material for each WAVE. However, CTSUM corresponds to 'wet' aerosol.
CATTNW	the total attenaution coefficient in square meters per milligram of 'wet' aerosol material.
CAY	the imaginary part of refractive index of dry aerosol. (Assumed to be negative; do not enter a value with a negative sign on the data card(s)).
CAYO	temporary storage.
CAYW	the imaginary part of refractive index of pure water at a given TEMP (DEG C) and WAVE.
CH	= FH/1-FH).
CONC	the mass concentration in gm/cc of a component of dry aerosol. It is the number of grams of dry aerosol per cubic centimeter of "cloud" or "fog", etc.
CONCT	the total mass concentration in mg/cc of dry aerosol.
CRGG	partial contributions to average radar cross section, for one

SYMBOL	Definition
CRHH	component of aerosol.
CRSUM	the average (sum/DENST) back-scattering cross-section in square micrometers, integrated over the size distribution, for each WAVE.
CRSUMT	value of radar corss section for total aerosol.
CJGG, CSHH	partial contributions to average scattering cross section for one component of aerosol.
CSSUM	the averge (sum/DENST) scattering cross-section in square micrometers, integrated over the size distribution, for each WAVE.
CTSUM	the average (sum/DENST) extinction cross-section in square micrometers, integrated over the size distribution, for each WAVE.
CTSUMT	the total extinction cross-section in square micrometers, integrated over the size distribution, for each WAVE.
DEL	fractional change in contribution to volume from n^{th} to $n+1^{st}$ halving, for one initial interval.
DELTA	convergence criterion.
DENS	the particle number density per cubic centimeter. See DENSC also.
DENSC	the particle number density per cc for each component of aerosol. It is calculated from mass density and concentration, and average volume per particle. If LLLL=1, the calculated value of DENSC is replaced by DENS, the value of which has been determined or supplied elsewhere.
DENST	the total particle number density per cc. See also DENSC.
DRYVOL	the average volume per particle in cc.
ELWC	the liquid water content in gm/cc.

SYMBOL	Definition
EM	the real part of the effective refractive index of 'wet' aerosol. See CAY EM = (EMW + (EMA - EMW)/A).
EMA	the real part of refractive index of the dry aerosol.
EMASS	is 'wet' mass concentration in gm/cc of a component of an aerosol when RELHUM and growth factor are non-zero. EMASS and CONC should have some value if growth factor is zero.
EMM	the refractive index of the surrounding medium, set equal to 1 here implying no surrounding medium.
EMUA	Hanel's mass accretion coefficient $\bar{\mu}$. Values must ve supplied by the user and depend on the type or composition of the aerosol being modeled as well as upon the value of the relative humidity.
EMW	the real part of refractive index of water at a given TEMR (DEG C) and WAVE.
F(I)	the normalized size distribution function (in micrometers^{-1}).
FF(J)	value of arbitrary distribution functions at radius RP = RLO * (J-1) + DELLR, J =1, NRADI.
FFT	contribution to integral of destribution function from one original interval.
FH	fractional relative humidity (saturation rates).
FKK	value of distribution function at radius R(KK).
FKKA	geometrical cross section of particle.
FT	partial contribution to integral of distribution function.
H( )	array containing angles.
IAPX	order of expansion for analytic phase function.
IDBLE	precision mode indicator.
IDSTP	identifies the type of aerosol size distribution being used in the run.

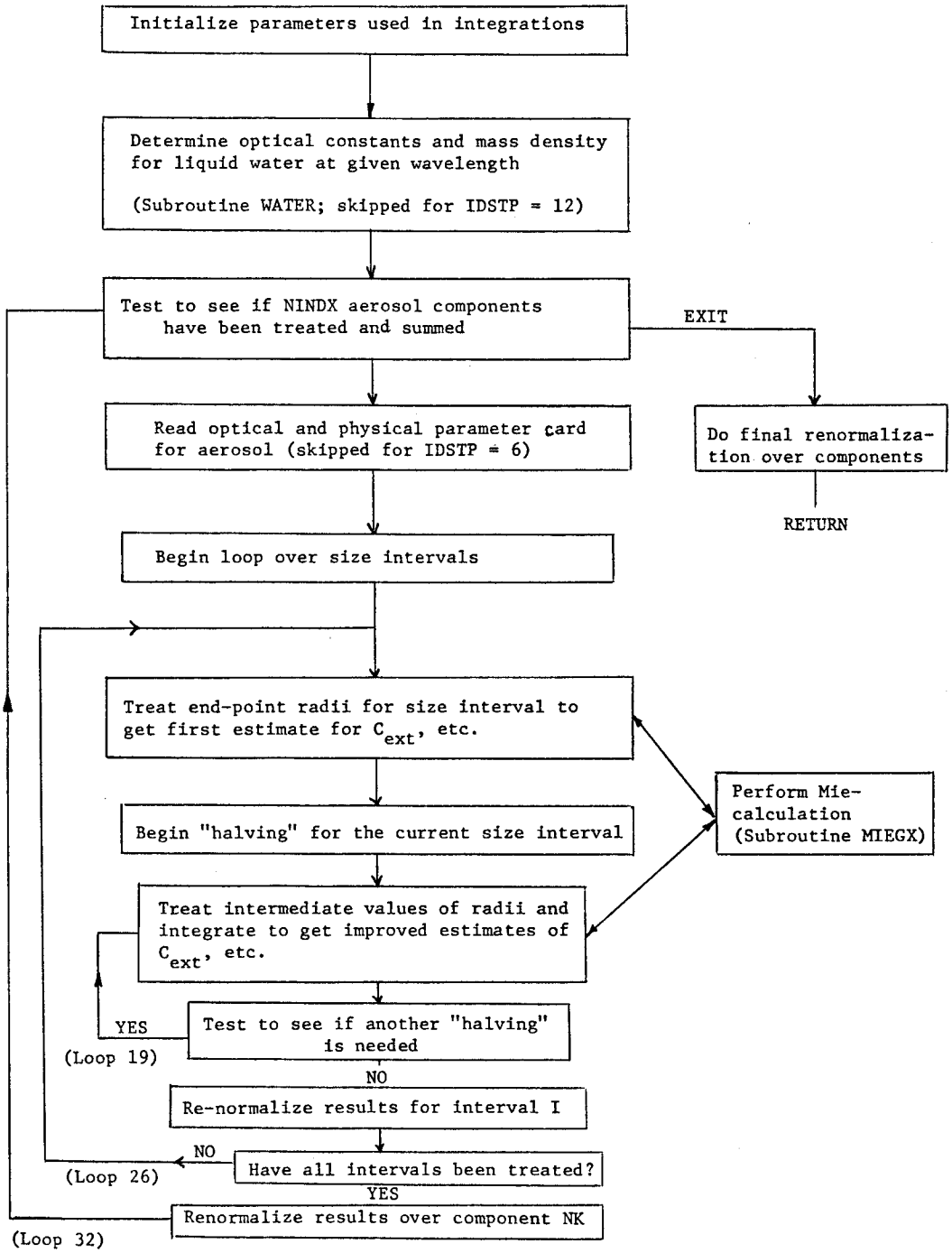
SYMBOL	Definition
IERROR	a flag which is set to unity if the number of terms reaches the maximum value allowed in the dimensions of the Mie-coefficients a_n and b_n.
KEXOLD	the extinction coefficient per km summed over the number of components one less than the current value of the running loop index NK.
KEXT	the extinction coefficient per km for each component of the aerosol.
KEXTT	the total extinction coefficient per km for each WAVE.
LLLL	a switch parameter. If LLLL=0, the particle number density (DENSC) is calculated using mass density and concentration, and the average volume per particle (DRYVOL). If LLLL=1, a pre-calculated or pre-supplied value of DENS is used.
MERROR	an error counter: If MERROR exceeds 10, execution is terminated.
MQRTE	= 12345, QT, QS, QR and Fr are printed for each radius.
NCRDS	not used in this subroutine, but appears in a common block.
NHALV	maximum number of interval halvings allowed for each initial interval.
NINDX	the number of aerosol components which will have different optical constants, mass density or mass concentration.
NRADI	the number of points on the radius vs. size distribution function plot.
01STAR	value of $\tilde{\omega}_1$ for a given size parameter.
01STRD	temporary storage for 01STAR.
02STAR	value of $\tilde{\omega}_2$ for a given size parameter.
02STRD	temporary storage for 02STAR.

SYMBOL	Definition
OL( )	Legendre coefficients.
OL1GG, OL1HH	partial contributions to average $\tilde{\omega}_1$, for one component of aerosol.
OL1HHT	contributes to $\tilde{\omega}_1$ of average particle from one original interval.
OL1SUM	value of $\tilde{\omega}_1$ for one component of an aerosol.
OL2GG, OL2HH	partial contributions to average $\tilde{\omega}_2$, for one component of aerosol
OL2HHT	contributions to $\tilde{\omega}_2$ of average particle from one original interval.
OL2SUM	value of $\tilde{\omega}_2$ for one component of aerosol.
OLSTAR	second Legendre coefficient $(\tilde{\omega}_1)$.
OM2	third Legendre coefficient $(\tilde{\omega}_2)$.
P(J)	an array containing 'IT' average intensity factors $(i_1 + i_2)/2$ for each radius.
PGG(I), PHH(I)	partial contributions to average intensity $(i_1 + i_2)/2$ for one aerosol component at abscessa value μ_I.
PHHT(I)	average intensity at μ_I for one original interval.
PL(,)	Legendre polynomials.
PSNEW(J)	= P(J)*F(L), where p(J) corresponds to L^{th} radius, $L \geq 2$.
PSOLD(J)	= P(J)*F(L), where P(J) corresponds to $(L-1)^{th}$ radius except when L=1; in that case PSOLD(J) = P(J)*FF(1), and P(J) corresponds to 1st radius.
PSUM(J)	average intensity factors integrated over the size distribution. They are then summed over NINDX components and divided by DENST.
PSUMT(J)	final average phase function.
QR	the back-scattering efficiency factor for each radius.
QRD	temporary storage for QR.

SYMBOL	Definition
QS	the scattering efficiency factor for each radius.
QSD	temporary storage for QS.
QT	extinction efficiency factor for a given size parameter.
QTD	temporary storage for QT.
R(L)	the array containing 'NRADI' values of radius in micrometers.
RELHUM	the relative humidity in percent.
RHO	the specific density (in gm/cc) of 'wet' aerosol.
RHOA	the specific density (in gm/cc) of 'wet' aerosol.
RHOW	the specific density (in gm/cc) of water at the temperature TEMP (in DEG C).
RIT	the radius of a particle after taking into account its growth due to absorption of water.
RR(I)	lower radius of I^{th} initial interval.
TEMK	the temperature of surrounding medium in degrees Kelvin.
TEMP	the temperature of the surrounding medium in degrees Centigrade.
TMASS	the total mass concentration in gm/cc of 'wet' aerosol.
TVOL	is used to pass the value of DRYVOL from MAIN to subroutine.
VOL	total volume occupied by aerosol material distributed in 1 cm^3 of space.
VOLGG	partial contributions to volume of average particle, for one
VOLHH	component of aerosol.
VOLHHT	contribution to volume of average particle from one original interval.
WAVE	the wavelength in micrometers at which all the scattering functions are computed.

Subroutine AGXPT2 - Simplified Flowchart

(Receives control data and size distribution data from main program)



SUBROUTINE AGXPT3

Subroutine AGXPT3 receives the values of various cross-sctions and the integrated average intensity factors from AGXPT2 and converts them into directly useful quantities:

$$\text{Coefficient (per km)} = 10^{-3}*\text{DENS}*\text{cross-section},$$

$$\text{Scattering fractions} = \frac{\lambda^2}{4\pi^2}*\text{DENS}*\text{intensity factors},$$

and $$\text{Phase function} = \frac{\lambda^2}{\pi C_{ext}}*\text{intensity factors}.$$

λ is in μm. It then prints out all single wavelength results.

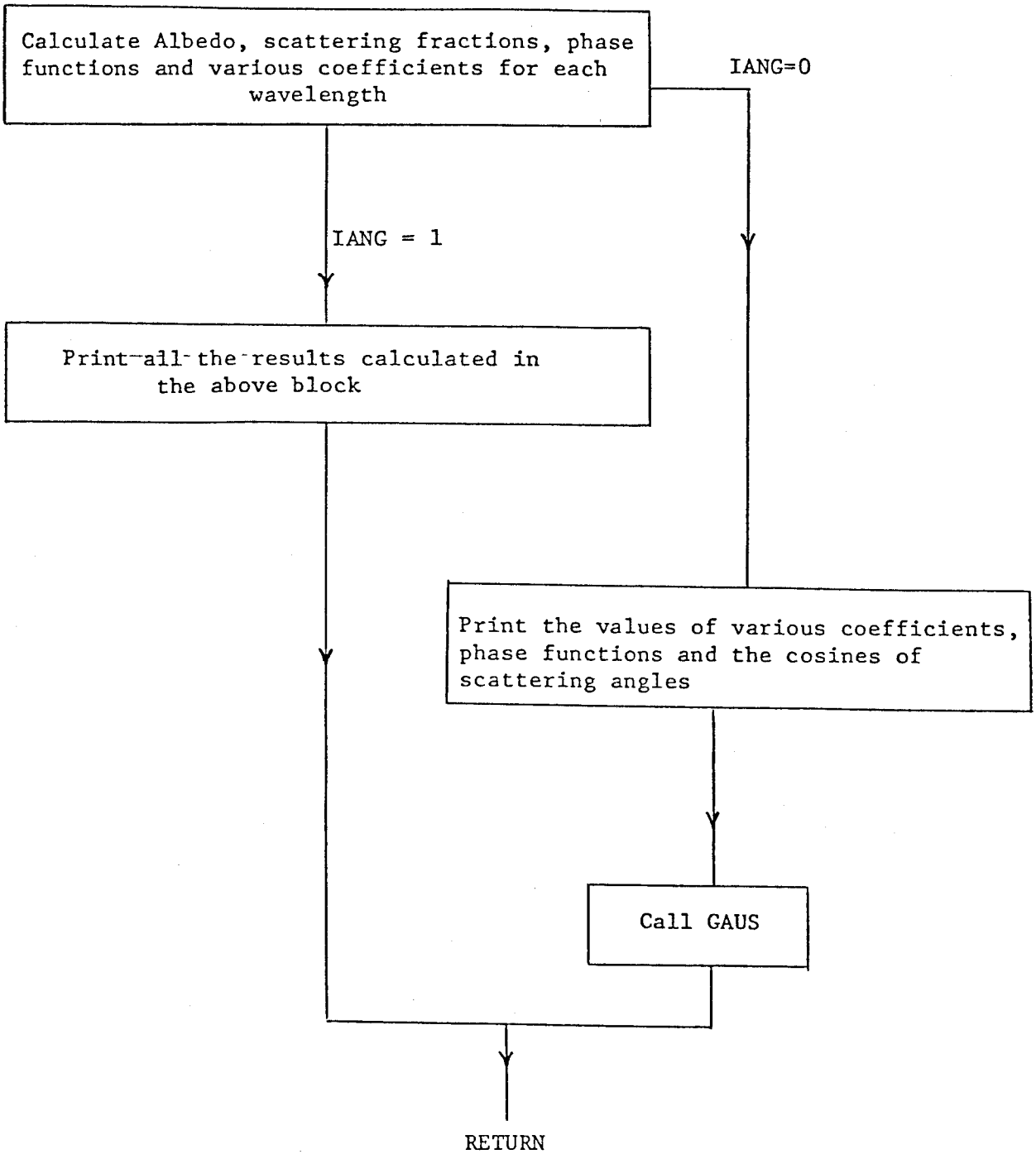
It also computes albedo for single scattering using equation (4). It then calls on subroutine GAUS which, among other things (see GAUS for details), also returns a value for albedo calculated differently. The two values are compared, and if they differ by more than 0.01 percent the user is advised to rerun the program using a larger value of IT.

SYMBOL	Explanation or Definition
ALBEDO	= CSSUM/CTSUM; albedo for single scattering.
C(I)	the cosines of scattering angles. 'IT' elements in the array.
CAY	the ratio of the imaginary part to the real part of adjusted refractive index of the last component.
CAYNG	= -CAY.
CRSUM	the average back-scattering cross-section when it is received by AGXPT3 but it returns to MAIN the value of the average scattering coefficient per km.
CSSUM	the average scattering cross-section when it is received by AGXPT3 but it returns to MAIN the value of the average scattering coefficient per km.

SYMBOL	Explanation or Definition
CTSUM	the average extinction cross-section when it is received by AGXPT3 but it returns to MAIN the value of the average extinction coefficient per km.
DENS	the total particle number density in cm^{-3}.
EM	the real part of the adjusted refractive index of the last aerosol component.
EMM	the refractive index of the surrounding medium. It is set equal to 1 in AGAUSX.
GNU	the wave number in cm^{-1}.
H(I)	the array containing 'IT' scattering angles (in degrees).
IANG	= 0, for computation of phase functions at 'IT' Gauss-Legendre quadrature angles. = 1, for computation of phase functions and scattering functions at 'IT' equally spaced angles between 0° and 180°. = 2, for computation of phase functions and scattering fractions at 'IT' user supplied angles.
IDSTP	identities the type of aerosol size distribution to be used.
IT	the order of expansion for phase functions when IANG = 0, the number of equally spaced angles between 0° and 180° when IANG = 1, or the number of user supplied angles when IANG = 2.
ITOT	used for optional write/punch on NUNIT.
KRSUM	the back-scattering coefficient per km integrated over the size distribution for each WAVE.
KSSUM	the scattering coefficient per km integrated over the size distribution, for each WAVE.

SYMBOL	Definition
KTSUM	the extinction coefficient per km integrated over the size distribution, for each WAVE.
NCRDS	= 1 for write/punch only Legendre coefficients on NUNIT: = 2 write only phase functions and scattering fractions on NUNIT: = 3 write/punch both on NUNIT.
NINDX	the number of aerosol components which will have different optical constants, mass density or mass concentration.
NUNIT	defines the device on which the input and/or output data may be stored in lieu of actual card punching; may be used to place nominal card output into data files on tape, etc. The default value (NUNIT = 0) is 4.
OL(1)	the first coefficient in the Legendre expansion of phase functions. When OL(1) disagrees with ALBEDO by more than 0.01 percent program AGAUSX should be rerun using a larger value of IT.
PFACT	= WAVE*WAVE/(PI*CTSUM*EMM*EMM). When PSUM(J) is multiplied by PFACT we get the original phase functions.
PSUM(J)	the average intensity factors integrated over the size distribution when received by AGXPT3, but they are the original phase functions for each WAVE when returned to MAIN.
SCAT(J)	contains 'IT' values of scattering fractions for each WAVE.
SFACT	= WAVE*WAVE*DENS*10^{-6}/4*PI*PI. When PSUM(J) is multiplied by SFACT, one gets the scattering fractions of ACT code.
WAVE	the wavelength in microns.

Subroutine AGXPT3 - Simplified Flowchart



SUBROUTINE MIEGX*

Subroutine MIEGX computes various efficiency factors, and intensity factors i_1 and i_2 for each complex refractive index m, size parameters α and also the first three Legendre coefficients ($\tilde{\omega}_o$, $\tilde{\omega}_1$, $\tilde{\omega}_2$) when IAPX is greater than zero. The Ricatti-Bessel functions and their derivatives in equations (5) and (6) are computed by the forward recursion method. The initial values used in forward recursion are:

$$\psi_o(z) = \sin z,$$

$$\psi_1(z) = \frac{\sin z}{z} - \cos z,$$

$$X_o(z) = \cos z, \text{ and}$$

$$X_1 = \frac{\cos z}{z} + \sin z.$$

[Note: $\xi_n(z) = \psi_n(z) + i\chi_n(z)$]

*A Mie-type routine utilizing a continued fractions method of calculation was obtained from W. J. Lentz of the Atmospheric Sciences Laboratory and modified slightly to substitute directly for MIEGX in AGAUSX, thereby eliminating the need for the forward recursion of the Ricatti-Bessel functions. The new routine is more accurate for larger Mie sizes and larger imaginary parts of the index of refraction. This new routine has been validated by New Mexico State University under contract DAAD07-79-M-6275. The rotation has been kept the same between the two routines as much as possible.

The angular functions π_n and τ_n are also computed by forward recursions from Equations (24) and (25). The initial values used are $\pi_o(\theta) = 0$, $\pi_1(\theta) = 1$, $\tau_o(\theta) = 0$, and $\tau_1(\theta) = \cos\theta$.

The Mie series is terminated either when two successive terms have $(|Re(a_n)| + |Im(a_n)| + |Re(b_n)| + |Im(b_n)|) < 10^{-5}$, or when the number of terms exceeds $(8 + F\alpha)$. F is 1.2 for $\alpha \leq 51$ and is $1 + 2.26\alpha^{-0.613}$ for $\alpha > 51$. The tolerance value of 10^{-5} could be decreased for higher precision, if the user so desires.

The subroutine computes and stores arrays of a_n and b_n until convergence is reached and then generates necessary π_n and τ_n functions. Finally it computes values of Q_{ext}, Q_{sca}, Q_{abs} (absorption) i_1, i_2, Q_{rad} (backscatter), $p(\theta)$, and radiation pressure Q_{pr}.

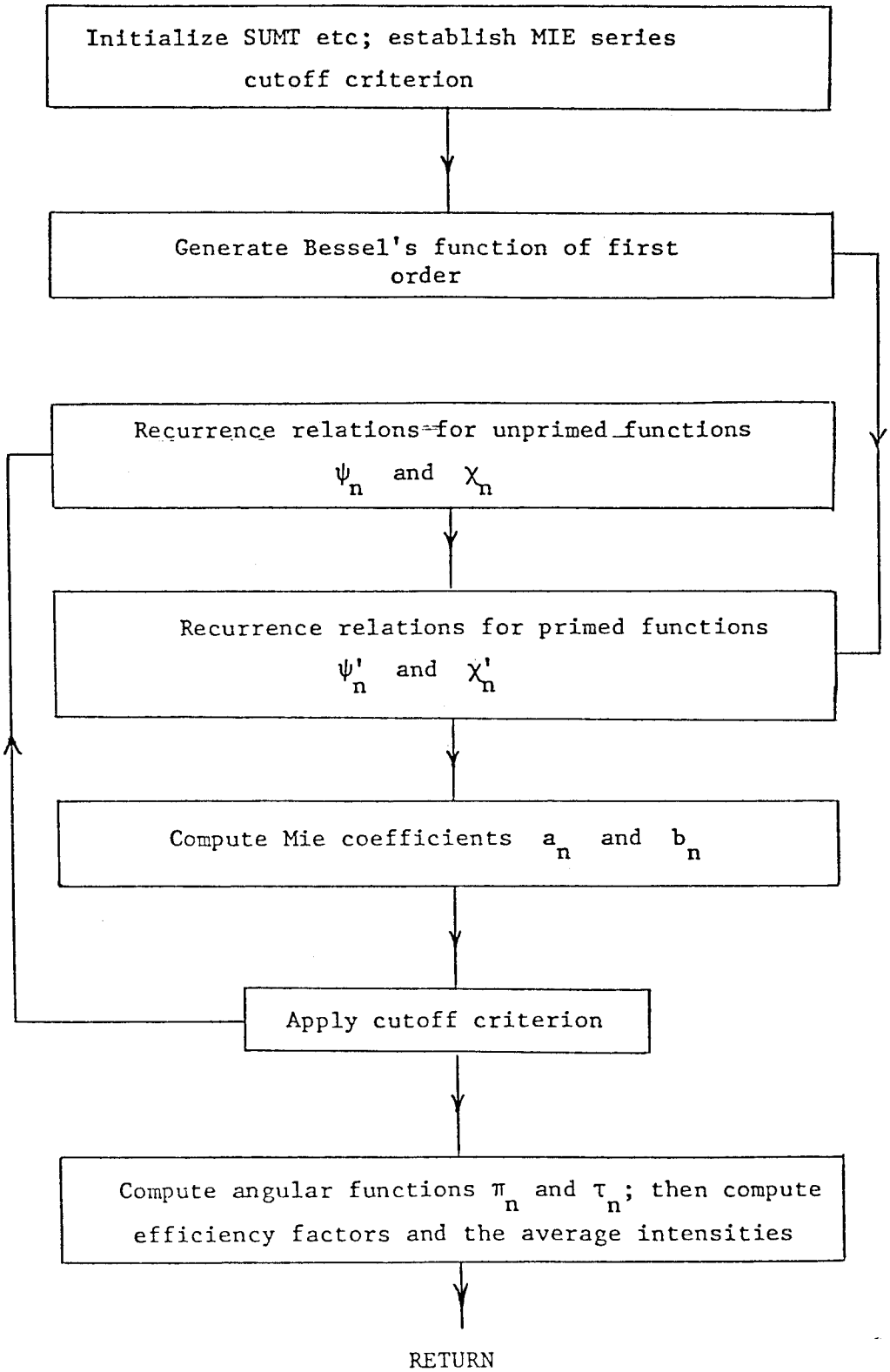
SYMBOL	Explanation or Definition
ALPHA	Mie size parameter, $\alpha = 2\pi r/\lambda$.
C(K)	the array of cosine of the scattering angles. There are 'IT' elements in the array.
CAY	the ratio of the imaginary part to the real part of adjusted refractive index. See AG9PT2.
EM	the real part of adjusted refractive index.
EN	floating point representation of N.
EYE1(K)	i_1(Eq. 15) at angles = Arc cos [C(K)]. 'IT' elements in the array.
EYE2(K)	i_2(Eq. 16) at angles = arc cos [C(K)]. 'IT' elements in the array.
FACT	determines the cutoff criterion to terminate the Mie series. It is equal to 1.2 if $\alpha \leq 51$ and is $1 + 2.26\alpha^{-0.613}$ for $\alpha > 51$. See Mie theory text.

SYMBOL	Definition
FAN(N)	= $Im(a_n)$; Equation (5).
FBN(N)	= $Im(b_n)$; Equation (6).
GAMMA	the true imaginary part of adjusted refractive index.
IERROR	a flag which is set to unity if the number of terms (N) reaches the maximum value allowed in the dimensions of a_n and b_n.
ISW1	a switch parameter used in applying cutoff criterion.
O1STAR	= $\tilde{\omega}_1$; first order coefficient for Legendre expansion of the average intensity P(K).
O2STAR	= $\tilde{\omega}_2$; second order coefficient for Legendre expansion of the average intensity p(K).
P(K)	= $(i_1 + i_2)/2$, the average intensity at angles, Arc cos (C(K)). There are 'IT' elements in the array.
PIN	= $\pi_n(\theta)$; Equation (17).
REAN	= $Re(a_n)$; Equation (5).
REBN	= $RE(b_n)$; Equation (6).
RN	= $Re(\psi_n(n\alpha))$; Equation (7).
RNL1	= $Re(\psi_o(n\alpha))$; Equation (7).
RPN	= $Re(\psi'(n\alpha))$. Prime indicates differentiation with respect to the argument.
SGA	the absorption efficiency factor.
SGMAS	the average value of $Cos(\theta)$, where θ is the scattering angle.
SGMP	the radiation pressure factor Q_{pr}.
SGR	the back-scattering efficiency factor.
SGS	the scattering efficiency factor.
SGT	the extinction efficiency factor.
SN	= $Im(\psi_n(n\alpha))$; Equation (7).

SYMBOL	Explanation or Definition
SNL1	$= \mathrm{Im}(\psi_o(n\alpha))$; Equation (7).
SPN	$= \mathrm{Im}(\psi'(n\alpha))$. Prine indicates differentiation with respect to the argument.
SUMI1I	the imaginary part of the scattering amplitude $S_1(\theta)$; $$\mathrm{ImS}_1(\theta) = \sum \frac{(2n+1)}{n(n+1)} [\mathrm{Im}(a_n)\pi_n(\theta)+\mathrm{Im}(b_n)\tau_n(\theta)].$$
SUMI2I	the imaginary part of the scattering amplitude $S_2(\theta)$; $$\mathrm{ImS}_1(\theta) = \sum \frac{(2n+1)}{n(n+1)} [\mathrm{Im}(b_n)\pi_n(\theta) + \mathrm{Im}(a_n)\tau_n(\theta)].$$
SUMI1R	the real part of the scattering amplitude $S_1(\theta)$; $$\mathrm{Re}\ S_1(\theta) = \sum \frac{(2n+1)}{n(n+1)} [\mathrm{Re}(a_n)\pi_n(\theta) + \mathrm{Re}(b_n)\tau_n(\theta)].$$
SUMI2R	the real part of the scattering amplitude $S_2(\theta)$; $$\mathrm{ReS}_2(\theta) = \sum \frac{(2n+1)}{n(n+1)} [\mathrm{Re}(b_n)\pi_n(\theta) + \mathrm{Re}(a_n)\tau_n(\theta)].$$
SUMRI	$= \sum_{n=1}^{N} (-1)^n(2n+1)\mathrm{Im}(a_n-b_n)$.
SUMRR	$= \sum_{n=1}^{N} (-1)^n(an+1)\mathrm{Re}(a_n-b_n)$.
SUMS	$= \sum(2n+1)(\lvert a_n\rvert^2 + \lvert b_n\rvert^2)$.
SUMS1	$= \sum_{n=2}^{N} \frac{(n-1)(n+1)}{n} [\mathrm{Re}(a_n)\mathrm{Re}(a_{n+1}) + \mathrm{Re}(b_n)\mathrm{Re}(b_{n+1}) + \mathrm{Im}(a_n)\mathrm{Im}(a_{n+1}) + \mathrm{Im}(b_n)\mathrm{Im}(b_{n+1})]$.
SUMS2	$= \sum_{n=1}^{N} \frac{(2n-1)}{n(n-1)} [\mathrm{Re}(a_n)\mathrm{Re}(b_n) + \mathrm{Im}(a_n)\mathrm{Im}(b_n)]$.
SUMT	$= \sum (2n+1)\mathrm{Re}(a_n + b_n)$.

SYMBOL	Explanation or Definition
TAUN	= $\tau_n(\theta)$; Equation (17).
TERMN	= $\lvert Re(a_n)\rvert + \lvert Im(a_n)\rvert + \lvert Re(b_n)\rvert + \lvert Im(b_n)\rvert$. TERMN determines the cutoff criterion for terminating Mie series.
TN	= $\psi_n(\alpha)$; Equation (7).
TNL1	= $\psi_o(\alpha)$; Equation (7).
TPN	= $\psi'(\alpha)$; prime indicates differentiation with respect to the argument.
UN	= $\chi_n(\alpha)$; Equation (8).
UNL1	= $\chi_o(\alpha)$; Equation (8).
UPN	= $\chi_n'(\alpha)$; prime indicates differentiation with respect to the argument.

Subroutine MIEGX - Simplified Flowchart



SUBROUTINE ANGLE

Subroutine ANGLE is called when IANG = 1 or 2. It is usd to compute the values of 'IT' equally spaced scattering angles between 0^0 and 180^0 or a read in set of user-supplied angles. It places these angle values in the array, H(I). It also computes the cosines of those angles and places them in the array C(I).

SYMBOLS	Explanation
C(I)	the array containing the cosines of scattering angles in the array H(I).
H(I)	the array containing !IT! scattering angles (in degrees).
IT	is the number of scattering angles chosen between 0^0 and 180^0.
RADS	=PI/180.

SUBROUTINE GUSET

Subroutine GUSET uses the Davis and Rabinowitz algorithm[11] to choose n values of $\cos\theta_{kn}$ (k = 1,2,...n) between the interval $-1 \leq \cos\theta \leq 1$ and the corresponding values of quadrature weights a_{kn}. The abcissas, $\cos\theta_{kn}$ are the n zeros of the Legendre polynomials $P_n(\cos\theta_{kn})$, while the weights are given by

$$a_{kn} = 2(1 - x_{kn}^2)/[nP_{n-1}(x_{kn})]^2 \qquad (65)$$

[11] P. Davis and P. Rabinowitz, 1956, J Res NBS, 56:35

Initial estimates of the zeros are obtained from the n successive zeros of the Bessel function ($j_o(j_k) = 0$) via

$$x_{kn} = \cos\left[j_k/\left((n + \tfrac{1}{2})^2 + (1 - (\tfrac{2}{\pi})^2)/4\right)^{1/2}\right]. \qquad (66)$$

final values of the x_{kn} are found by Newton-Raphson iteration. The tolernace of Legendre polynomial zeros is set at 10^{-14}.

SYMBOL	Explanation
AKN(k)	a_{kn} (Eq. 32). 'IT' elements in the array.
IT	n; it is the order of Legendre expansion for phase functions.
P(N)	Legendre polynomials, $p_n(x)$.
X	x_{kn} (Eq. 33).
XKN(K)	$\cos\theta_{kn}$; $P_n(\cos\theta_{kn}) = 0$ within 10^{-14}.
TOL	the tolerance of zeros of Legendre polynomials = 10^{-14}.
Z(I)	j_k (Eq. 33). I, k = 1,2,...IT.

SUBROUTINE GAUS

Subroutine GAUS computes the Legendre polynomials as PL(,) and computes Legendre expansion coefficients given by equation (31) numerically. To do that the integral in equation (31) is replaced by summation as follows:

$$\tilde{\omega}_\ell = \frac{(2\ell+1)}{2} \sum_{k=1}^{n} p(\theta_{kn}) p_\ell(\cos\theta_{kn}) a_{kn},$$

where θ_{kn} and a_{kn} have the meaning as given in subroutine GUSET.

Using the values of coefficients $\tilde{\omega}$ and equation (30), the phase functions are reconstructed and called $p_c(\theta_{kn})$. GAUS then computes the root mean square deviation between the original phase functions $p(\theta_{kn})$ and the reconstructed phase functions $p_c(\theta_{kn})$ as each successive term is added to the series in equation (30). Finally it prints out the values of coefficients and rms deviations.

SYMBOL	Explanation or Definition
F	is the array containing the original phase function $p(\theta_{kn})$.
IT	is the order of Legendre expansion for phase functions.
NCRDS	= 1 for write/punch only Legendre coefficients on NUNIT: = 2 write only phase functions and scattering fractions on NUNIT: = 3 write/punch both on NUNIT.
NUNIT	defines the device on which the input and/or output data may be stored in lieu of actual card punching; may be used to place nominal card output into data files or tape, etc. The default value (NUNIT=0) is 4.
OL(LL)	the array containing coefficients $\tilde{w}_\ell$.
PL(,)	Legendre polynomials (equivalenced in MIEGX).
PC(I)	the array containing the reconstructed phase functions $p_c(\theta_{kn})$.
RMS(J)	the rms deviation between the original phase functions and the reconstructed phase functions.

SUBROUTINE WATER

The purpose of subroutine WATER is to relieve the user of program AGAUS of the task of looking up and keypunching data on the index of refraction and mass density of liquid water. This routine receives the wavelength (μm) and temperature (°K) from the calling program as variables WVD and TEMPD. It returns the mass density through variable DENSD, and the real and imaginary parts of the refractive index of liquid water through the variables EMD and CAYD, respectively.

The data on optical constants coded into routine WATER were taken from the tabulation by Irvine and Pollack[9] and the water densities were taken from a copy of the CRC Handbook of Chemistry and Physics. Tabulated values of the real (m) and imaginary (k) parts of the refractive index are available for the wavelength range 0.20μm to 200μm, and are entered at uniform wavelength increments. Values of the real (m) and imaginary (k) parts of the refractive index at wavelengths other than found in the table are estimated through straight-line interpolation. Linear interpolation is also used between tabulated temperatures in calculating the mass density ρ_w (= DENSD).

Methods Used

Subroutine WATER conducts separate binary searches of the wavelength table LAMBDA() and temperature table TEMP() to find the indices L and L+1 which bracket the received wavelength (WVD) and temperature (TEMPD). It then uses linear interpolation to get estimated values of EMT, (M), CAYT, (k), and RHODEN (ρ_w).

The interpolation formula can be written as

$$y(x) = y(x_\ell) + \left[\frac{y_{\ell+1}-y_\ell}{x_{\ell+1}-x_\ell}\right](x-x_\ell),$$

with y = m, k or ρ_w and x = wavelength or temperature.

---

[9] W. M. Irvine and J. B. Pollack, 1968, "Infrared Optical Properties of Water and Ice Spheres," Icarus, 8:324

SYMBOL	Explanation or Definition
CAYD	imaginary part of refractive index k.
CAYT	the interpolated value of k in single precision form; used intermediately to hold summed quantities.
DENSD	interpolated result for the mass density of liquid water - ρ_w .
EMD	real part of index of refraction - m .
EMT	the interpolated result for the real part of the refractive index .
H	an indexing (integer) parameter.
L	an integer indexing parameter.
LAMBDA ( )	array of wavelengths at which data are entered for m and k; [typed as "real"].
NSUBI( )	array of values for k (or, $n_{imaginary}$); [typed as "real"].
NSUBR	array of data entries for m (or, n_{real}) [typed as "real"].
P	an (integer) indexing parameter.
POINT	an (integer) indexing parameter.
TEMP( )	array of temperature values (°K) at which entries for ρ_w exist .
TEMPD	temperature at which ρ_w is to be found .
TMCHUR	temperature at which value of ρ_w is desired.
RHODEN	interpolated result for ρ_w .
WAVE	single precision version of wavelength at which values of n and k are desired.

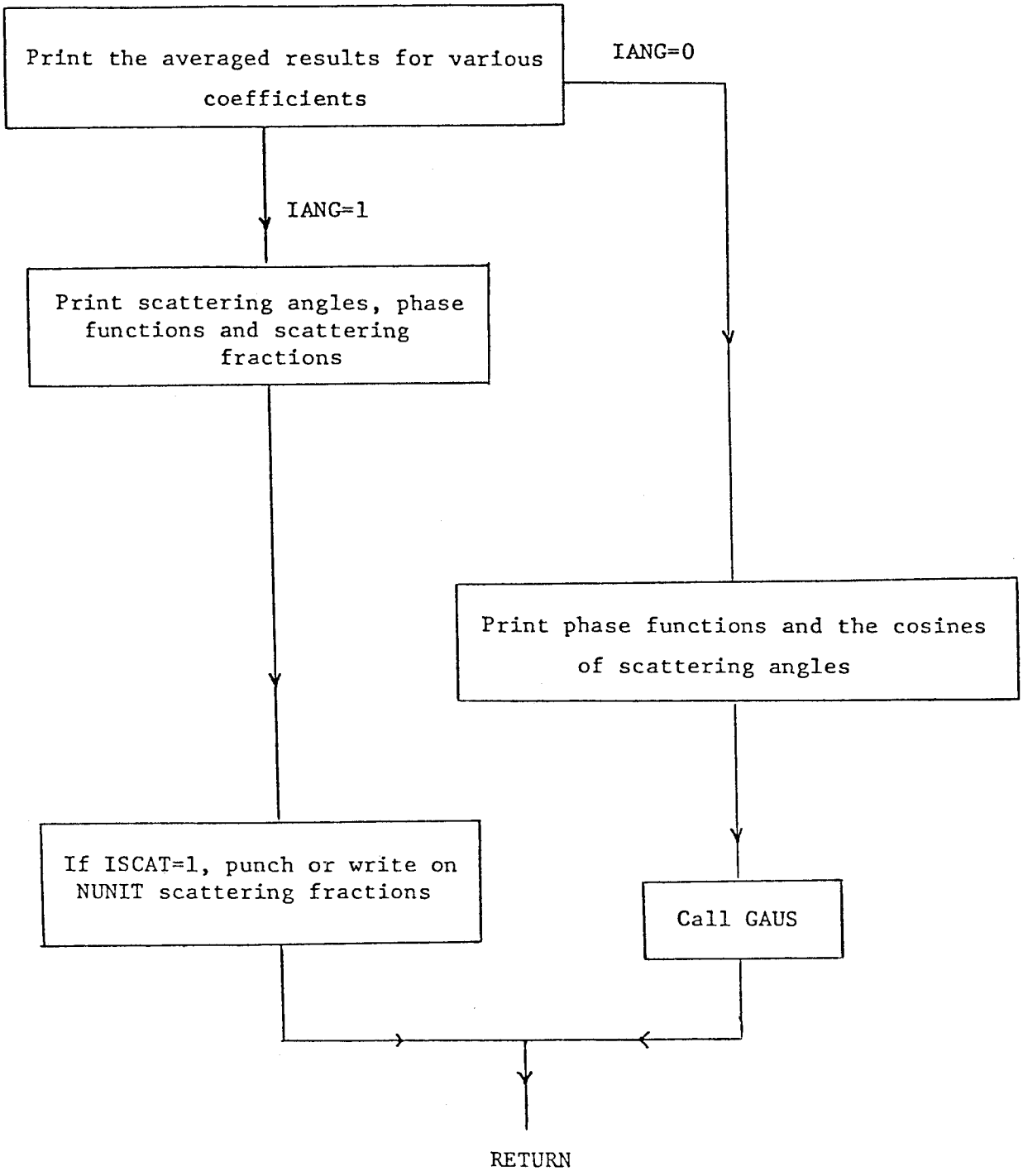
SUBROUTINE AGXPRT

Subroutine AGXPRT prints out all the averaged (sum/NWAVE) results essentially in the same way as AGXPT3 does for each wavelength if IAPX = 0. If IANG = 0, subroutine GAUS is called to generate Legendre expansion coefficients which are used to reconstruct the averaged phase functions. GAUS also computes the root mean square deviation between the original phase function and the reconstructed phase functions. See the section on subroutine GAUS for more details. If IANG = 1 or 2, the above calculation is skipped.

SYMBOL	Explanation or Definition
C(I)	the cosines of scattering angles. 'IT' elements in the array.
CATTN	the average (sum/NWAVE) attenuation coefficient in square meters per milligram of aerosol material.
H(I)	the array containing 'IT' scattering angles (in degrees).
IANG	= 0, for the computation of phase functions at 'IT' Gauss-Legendre quadrature angles. = 1, for the computation of phase functions and scattering fractions at 'IT' equally spaced angles between 0° and 180°.
IT	the order of Legendre expansion for phase functions when IANG = 0, or the number of equally spaced angles between 0° and 180° when IANG = 1, or the number of user-supplied angles when IANG = 2.
KBAKT	the average (sum/NWAVE) back-scattering coefficient per km, integrated over the size distribution.
KEXTT	the average (sum/NWAVE) extinction coefficient per km, integrated over the size distribution.
KSCAT	the average (sum/NWAVE) scattering coefficient per km, integrated over the size distribution.

SYMBOL	Explanation or Definition
NUNIT	defines the device on which the input and/or output data may be stored in lieu of actual card punching; may be used to place nominal card output into data files on tape, etc. The default value (NUNIT=0) is 4.
NWAVE	the number of wavelengths or relative humidity values to be treated in a given run.
PSUM(J)	the array containing the values of average (sum/NWAVE) phase function integrated over the size distribution.
SCATT(J)	the array containing the values of average (sum/NWAVE) scattering fractions.

Subroutine AGXPRT - Simplified Flowchart



SUBROUTINE GPHASX

Subroutine GPHASX constructs the GHG analytic phase function. The required input consists of the phase function at zero degrees, $\tilde{\omega}_o$, $\tilde{\omega}_2$, and the order of Legendre expansion, L. The parameter g, denoted by G1 in the subroutine, is then determined by an iterative process: note $0 \leq g \leq 1$. We then determine α and subsequently proceed to construct the GHG phase function, checking to insure that the phase function does not go negative; if it does, we leave the current loop and starting from the previous value of μ (for which the phase function was positive), continue to construct the GHG phase function from the modified HG phase function. The GHG phase function is then renormalized and the appropriate Legendre coefficients are constructed.

SYMBOL	Explanation or Definition
ALPHA	$.5[\tilde{\omega}_2/(\tilde{\omega}_o G^2)-1]$.
C	$P(1)/\tilde{\omega}_o$.
COEF	Array containing first three Legendre coefficients ($\tilde{\omega}_o$, $\tilde{\omega}_1$, $\tilde{\omega}_2$).
DELL	Iterative increment in determination of G
DEN	$1 + G^2 - 2\mu G$; $\mu = \cos\theta$.
DENOM	$(1 + G^2 - 2\mu G)^{1/2}$.
ELHS	$G[(1 - G^2)P(1)/\tilde{\omega}_o - 1 + 3G/2]$.
EMO	Array containing Gauss-Legendre angles.
EMU	Array containing cosines of Gauss-Legendre angles.
ERR	Error in integrated GHG phase function.
G	Parameter in GHG phase function.
GPFN	Array containing GHG phase function.

SYMBOL	Explanation or Definition
GSQ	G * G.
ITR	number of iterations in the determination of G; 100 iterations maximum.
NUNIT	Auxiliary unit for writing/punching Legendre coefficients for GHG phase function.
OM	Array containing GHG phase function Legendre coefficients.
OMO	Approximate $\tilde{\omega}_o$.
PA	Array of temporary values needed in subroutine GUSSTX.
PHASEO	GHG phase function at zero degrees.
PL	Array containing Legendre polynomials.
PSUM	Array containing true phase function at zero degrees; PSUM(1).
RHS	$.5\ \tilde{\omega}_2/\tilde{\omega}_o$.
SUM	integrated GHG phase function.
TRUEG	Asymmetry factor = $\tilde{\omega}_1/(3\tilde{\omega}_o)$.
W	Array containing weights for Gauss-Legendre integration.

SUBROUTINE GUSSTX

This subroutine is essentially the same as GUSET: please see GUSET for details.

SUBROUTINE PRINTX

Subroutine PRINTX prints out various quantities for the analytic GHG phase function. It will also punch out the Legendre coefficients for the GHG function.

SYMBOL	Explanation or Definition
COEFS	Array containing GHG Legendre coefficients.
EMU	Array containing cosine of Gauss-Legendre angles.
ERROR	Percent error in the GHG integrated phase function.
G	Asymmetry factor; $\tilde{\omega}_1/(3\tilde{\omega}_o)$.
NUNIT	Auxiliary unit for writing (punching) GHG Legendre coefficients.
PHASE	GHG phase function at zero degrees.
PHFN	GHG phase function.
PSUM	Array containing true phase function at zero degrees.
SUM	GHG integrated phase function.

INPUT DATA

There are nominally four data and control cards required for running program AGAUSX.

CARD	General Description
I	A set of integers which select certain options available within the program.
IA	A user set of supplied angles.
II	A set of data describing the parameters of the particular size distribution function to be used. For cases other than the user-supplied "arbitrary" distribution (IDSTP = 0), only one card of this type is needed.
IIIA	A set of data describing the initial wavelength (μm) to be used, its increment, aerosol number density (particles per cc), relative humidity (percent), atmospheric temperature (degrees centigrade), and the desired convergence testing level.
IIIB	If the looping option for relative humidity is invoked then NWAVE-1 cards containing relative humidity and atmospheric temperature must be added.
IV	A set of data describing the optical and physical properties of the aerosol material. If the aerosol is a mixture of materials of unlike properties (NINDX > 1), more than one card of this type is needed for each card of type III. No card of this type is used, however, for runs with parameter IDSTP equal to 6.

Remarks:

1. The simplest type of run (IDSTP=6, water cloud or fog model) requires one card each of types I, II, and III. Forother IDSTP choices, at least one card of type IV is also needed.

2. If the run is to use several wavelengths (NWAVE > 1), then at least one card of type IV is required for each wavelength (more than one type IV card will be needed at each wavelength if the aerosol is a multicomponent mixture - NINDX > 1).

3. Two special "looping" modes of AGAUSX affect the number of cards of type III which are needed:

a. For runs at constant relative humidity and several wavelengths, only one type III card is permitted. To activate this mode, the wavelength increment DWAVE on card type III must be larger than 10^{-4}.

b. Runs at constant wavelength and a set of differing values of relative humidity require one card of types IIIA and IV for the first value of relative humidity; subsequently NWAVE-1 cards of types IIIB and IV are needed for each additional value of relative humidity. This option is invoked by setting the parameter "DWAVE" less than 10^{-4} on the first card of type IIIA.

Description of Types of Distributions

IDSTP	DESCRIPTION
0	This is an arbitrary user-supplied distribution. 'NRADI' + 1 cards will be read; the first card contains RLO and DELLR (μm). The rest of the cards carry the values of F(J) and must be in order of increasing radius value.
1	This is the zero-order log-normal distribution: the distribution function is given by

$$F(R) = \frac{1}{\sqrt{2\pi}\ \log_e(\sigma)R}\ \exp\{-\frac{1}{2}\ [\frac{\log_e(R/\bar{R})}{\log_e(\sigma)}]^{1/2}\}.$$

R ≡ RBAR; σ ≡ SIGMA, is the standard deviation. This distribution type requires one input data card to read in the values of $\bar{R}$, σ, RLO and RHI.

2 This is called the double exponential distribution and its distribution function is given by F(R) = QA exp(-AR) + (1-Q)B exp(-BR). Q ≡ CUE. This distribution type requires one input data card to read in the values of RLO, RHI, Q, A, and B. Q is dimensionless while A and B have units of μm^{-1}.

3 This model (Deirmendjian's "Model C") does not require any input data card. It carries fixed value of DENS, RLO, and DELRD. RHI is determined by the input parameter NRADI.

$$F(R) = 450.2 \qquad R \leq .08$$
$$= 2.251*DELRD*R^{-4} \qquad R \geq .08$$

4 The distribution function of this model (Junge distribution) is given by $F(R) = QR^{-A}$, Q ≡ CUE. This distribution type requires one input data card to read in RLO, RHI, A, A.

5 The distribution function for the Modified Gamma/Generalized Khirgian-Mazin distribution is

$$F(R) = R^{\alpha} \exp\ [-(\frac{R}{R_c})^{\gamma} \cdot \frac{\alpha}{\gamma}],\ \alpha \equiv ALF,\ \gamma \equiv GAM,\ \text{and}$$

$R_c \equiv$ RC. One input card is needed to readin RLO, RHI, RC, ALF, GAM, and ELWC. ELWC is not needed for type 5 distribution and therefore can be left blank.

6 The size distribution model (NMSU Fog or Cloud Model) is very similar to type 5, except that the user must supply one additional input parameter--namely, the liquid water content (ELWC) in gm/cc. This model can be used for treating situations involving liquid water aerosols like clouds or fogs. For type 6 runs one does not need to read in the values of EMA, CAYA, RHOA, CONC.

7 This distribution is essentially same as Junge's distribution (type 4) except that it has fixed parameters. One input card is needed to read in VIS (visibility in km); VIS is used in calculating DENS.

8 This is a fixed parameter Continental Bi-modal Model. It does not require an input data card.

9 This is a fixed parameter Maritime Bi-modal Model. It does not require an input data card.

10 This is a fixed parameter Urban Bi-modal Model. It does not require an input data card.

11 This is a user-supplied Bi-modal Model. This requires one input card to read in FOA, FOC, SGA, SGC, RBARA, RBARC. Types 8, 9, 10, and 11 use the sum of two log-normal distributions:

$$F(R) = \sum_{i=1}^{2} \frac{N_i}{\sqrt{2\pi}\ \log_e(\sigma_i)R} \exp\left\{ -\frac{1}{2} \frac{\log_e(R/\bar{R}_i)}{\log_e(\sigma_i)} \right\}^2$$

$N_1 \equiv$ FOA, $\bar{R}_1 \equiv$ RBARA, $\sigma_1 \equiv$ SGA with similar meaning for N_2, $\bar{R}_2$, and σ_2. Note that in Type 8, 9, 10 the values of SGA and SGC are $\log_e(\sigma)$.

12 This model (Marshall-Palmer Rain Model) is a simple exponential model which assumes an empirical relationship between rain rate and droplet size distribution parameters:

$$F(D) = N_o \exp(-\Lambda D).$$

$N_o = 0.08\ cm^{-4}$, and $\Lambda = 41(RN)^{-0.21}$ in which RN = RAIN is the rain rate in mm/hour. Diameter D is in cm. The corresponding size distribution function of radius R is given by

$$F(R) = 2N_o \exp(-2\Lambda R).$$

This distribution requires one input data card to read in RAIN. The values of RLO and RHI are fixed at 0 and 0.5 cm respectively. Due to the limitations on the range of Mie-sizes (subroutine MIEGX) type 12 usage is limited to wavelengths of the order of 1 mm or larger. Since subroutine WATER does not contain optical data for wavelengths longer than 0.2 mm, type 12 runs require the user to supply the values of EMA, CAYA, and RHOA as if rain were a non-aqueous aerosol.

SUMMARY OF DATA CARD REQUIREMENTS

CARD TYPE	INPUT SYMBOLS
I	Integer control parameters: NWAVE, NINDX, IW, IDSTP, NRADI, IT, IANG, NCRDS, ITOT, MQRTE, IAPX, FORMAT (1215).

NWAVE: is the number of wavelengths, or relative humidity values to be treated in this run. See comments circa read of WAVE, DWAVE, etc.

NINDX: is the number of aerosol components which will have different optical constants, mass densities or mass concentrations.

IW: = 0 will set the refractive index of the dry aerosol equal to that of water at the input wavelength and temperature - see Card 4, EMA, CAYA.

IDSTP: Identifies type of aerosol size distribution to be used.

NRADI: Number of particle radii to be expected for IDSTP = 0 or 3: the input value of NRADI is ignored for IDSTP not zero or 3. NRADI must be less than 513.

IT: is the number of Gauss-Legendre angles (order of expansion) if IANG = 0 or number of angles between 0 degrees and 180 degrees if IANG = 1. If only extinction coefficients, etc. are desired, i.e., not phase functions, then set -IT- equal to one.

IANG: = 0 for computations of phase function at -IT- Gauss-Legendre quadrature angles: no scattering fractions will be printed. IANG = 1 for computations of scattering fractions and phase functions at -IT- equally spaced angles between 0 and 180 degrees. IANG = 2 will allow -IT- user supplied angles to be read - FORMAT (16F5.1). This requires at least one card of type IA.

CARD TYPE	INPUT SYMBOLS
I	NCRDS: = 1 write/punch Legendre coefficients and order of expansion on NUNIT - FORMAT (D25.14,1X,15): = 2 write/punch scattering fractions, phase functions, cosines and counter on NUNIT - FORMAT (3(D12.61X),15): = 3 write/punch both scattering fractions, phase functions, cosines, counter, and Legendre coefficients and order of expansion on NUNIT - FORMATS (3(D12.6.,1X),15) and (D25.14,1X,15): scattering fractions, phase functions, cosines and counter (respectively) are always written/punched before the Legendre coefficients and order of expansion (respectively).
	ITOT: Works in conjunction with NCRDS and NWAVE to write/punch either individual wavelength values or averaged wavelength values or both on NUNIT: = 1 for individual wavelengths; = 2 for averaged wavelengths; = 3 for both.
	NUNIT: defines device number. See previous comment card.
	MQRTE: = 12345 will cause prints of Mie efficiency factors at every value of particle radius used in the Mie calculations; set MQRTE = 0 if such prints are not desired.
	IAPX: if GT zero the GHG (analytic) phase function will be constructed at IAPX Gauss-Legendre angles (order of expansion).
IA	User supplied set of -IT- angles FORMAT (16F5.1) 16 values per card, more than 1 card may be needed. This card is only needed when IANG = 2.

CARD TYPE	INPUT SYMBOL
II	Distribution parameters: only one type per run. FORMAT (6E12.6). For a more detailed description of these parameters see the previous discussions in AGXPT1. All units are in micrometers.
	TYPE 0. USER SUPPLIED - NRADI + 1 CARDS
	RLO, DELLR
	FF(I), I = 1, NRADI
	TYPE 1. LOG-NORMAL
	RBAR, SIGMA, RLO, RHI
	TYPE 2. DOUBLE EXPONENTIAL
	RLO, RHI, CUE, A, B
	TYPE 3. DEIRMENDJIAN MODEL C
	- NO INPUT -
	TYPE 4. POWER LAW (JUNGE)
	RLO, RHI, CUE, A
	TYPE 5. MODIFIED GAMMA
	RLO, RHI, RC, ALF, GAM, ELWC
	TYPE 6. MODIFIED GAMMA FOG MODEL
	RLO, RHI, RC, ALG, GAM, ELWC
	TYPE 7. POWER LAW
	VIS
	TYPE 8. CONTINENTAL BIMODAL
	- NO INPUT -
	TYPE 9. MARITIME BIMODAL
	- NO INPUT -

CARD TYPE	INPUT SYMBOLS
II	TYPE 10. URBAN BIMODAL
	- NO INPUT -
	TYPE 11. USER SUPPLIED BIMODAL
	FOA, RBARA, GSA, FOC, RBARC, SGC
	TYPE 12. MARSHALL-PALMER RAIN MODEL
	RAIN
III	Control Parameters: FORMAT (6E12.6) WAVE, DWAVE, RELHUM, DENSH, TEMP, DELTA. For looping over different values of relative humidity set DWAVE = 0, and add NWAVE - 1 cards containing RELHUM and TEMP. FORMAT (2E12.6).
	WAVE: is wavelength in micrometers
	DWAVE: is the wavelength increment in micrometers. If DWAVE is less than 1.E-4, a special case applies used for looping over NWAVE values of RELHUM. For example in that case a card which carries the value of RELHUM and TEMP must be repeated NWAVE - 1 times; the first card of this type must contain WAVE, DWAVE, RELHUM, DENSH, TEMP and DELTA.
	RELHUM: is relative humidity in percent.
	DENSH: is particle number per cubic centimeter. User-supplied value of DENSH will be ignored for IDSTP = 3 or greater than 6 because those distributions carry pre-determined density values. Also, if DENSH is less than 1E-4, the particle number density will be calculated from mass densities and mass concentrations.

CARD TYPE	INPUT SYMBOLS
III	TEMP: is the temperature of the atmosphere in degrees C. DELTA: is the convergence criterion. Within a particular size range interval, halving is terminated when the quantity DEL is less than DELTA.
IV	Optical and physical data (Read in AGXPT2) FORMAT (4F10.6E15.7) EMA, CAYA, EMUA, RHOA, CONC. EMA: is the real part of the index of refraction of dry aerosol. CAYA: is the imaginary part of refractive index for dry aerosol. CAYA is assumed to be negative: do not enter CAYA with a negative sign. EMUA: is Hanel's growth factor (ME-BAR)/accretion coefficient. RHOA: is the mass density (sp. GRAV) of dry aerosol. CONC: is the mass concentration (GM/CC) of dry aerosol. For looping over wavelength or relative humidity repeat this card NWAVE times and interleave with card 3: For looping over aerosol components also repeat nindx times. This card is not needed when IDSTP = 6. Also if IW = 0 EMA and CAYA will internally be set equal to the refractive index of water and therefore may be left blank: values for EMUA, RHOA, and CONC may be necessary to supply, depending upon the users needs.

Remarks:

1. Card Type IV is not required and is never read-in if IDSTP = 6 (water cloud/for model) since the relevant data are obtained from subroutine WATER.

2. In the case IDSTP = 12, the rain model, card type IV must carry the optical data for liquid water as EMA and CAYA. The reason for that inconsistency is that the rain model will most likely be useable at

wavelengths for which no data appear in subroutine WATER (restricted to $\lambda \leq 0.2$mm). [The large droplet sizes to be found in the rain model will usually cause premature failure of the Mie routine at small wavelengths.]

3. Card type IV, with appropriately adjusted data values, must be repeated (NWAVE - 1) times.

4. EMA and CAYA may be left blank on Card type 4 when IW = 0 as they will internally be set equal to the value for water.

Incidental Remarks Regarding AGAUSX

(1) In AGAUSX, the average "dry volume per particle" is found using all available values for particle radii. It may differ from that printed in routine AGXPT2 since that routine might not proceed to the use of all available values.

(2) The "volume" convergence tests in AGXPT2 use the volume inferred after any growth arising from non-zero saturation ratios has been included.

(3) It should be noted that the convergence tests used in AGAUSX do not really provide tests of the absolute accuracies achieved for the tested quantity. It is possible for "exit" to occur ($\delta<\Delta$) even though the use of "another" halving might lead to $\delta>\Delta$ again. If runs using some choice of Δ might lead to what appear to be "unusual" or unexpected results, it is advised that, as a test, the case be re-run using a smaller value of Δ.

(4) Some users may wish to explore possible increases in computation efficiency which might result from changes in the number (NI) of size-intervals, or, the ways in which they have been chosen (in AGXPT1).

Comments on Usage of AGAUSX in the IANG = 0 Mode

AGAUSX has been coded to preserve the option of creating the expansion coefficients, $\tilde{\omega}_\ell$, which are needed by the multiple scattering codes STAR04, AGSCAT, and the thermal emission code CLEM70(8). Usage of the $\tilde{\omega}_\ell$ coefficients for the above purposes, however, requires some caution on the part of the user. In particular, users must not assume that the absence of abnormal termination of runs of AGAUSX guarantees that "all is well". Past experience has shown that "warnings" of possible problems printed by those programs may not be noticed or taken very seriously. In an attempt to overcome those oversights, additional tests and warnings have been incorporated in AGAUSX. If those warnings are to be meaningful, users should examine printed outputs carefully for such warnings before using the results of runs as inputs to subsequent codes.

One particular point which should be checked is to see that the quantity printed under the heading ALBDO agrees reasonably well with the zeroth coefficient ($\tilde{\omega}_0$) of the expansion coefficients. Substantial disagreement between those two quantities usually means that the parameter "IT" used in a run was too small to achieve a really accurate reconstruction of the phase function from only "IT" Legendre expansion terms.

Should possible inaccuracies be found, please contact R. C. Shirkey, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico 88002 .

SAMPLES OF INPUT AND OUTPUT FOR AGAUSX

INPUT

The subsequent output section is based upon the following input.

Example 1: IDSTP = 0 (User supplied distribution data)

Column 5

```
   2    1    9    0    11   5    0    0    0    012345    0
0.10000E-00 0.0200E+00
0.00000E-00
0.20000E-00
0.40000E-00
0.60000E-00
0.80000E-00
1.00000E-00
0.80000E-00
0.60000E-00
0.40000E-00
0.20000E-00
0.00000E-00
10.6000E+00 0.10000E-05  00.0000E+00 0.00000E-05  25.0000E+00 1.00000E-02
   1.9530   .46800    0.00000    1.87000   1.000000E-09
75.0000E+00 25.0000E+00
   1.9530   .468000   0.15900    1.87000   1.000000E-09
```

This example is set up to read 11 distribution data cards, and to run for two values of relative humidity at λ = 10.6μm. Since MQRTE = 12345, detailed Mie results for each of the 11 radii will be printed. Parameter 'IT' is 5, IANG = 1. Note that the second data card contains RLO (= 0.1μm) and DELLR (= 0.02). The next eleven cards contain F(RLO), F(RLO + DELLR, etc.). The remaining cards consist of two pairs of cards, two for each of the two values of NWAVE. In all cases, DENSH is zero which means that particle number densities will be calculated from RHOA (1.87, above), CONC (10^{-9} gm/cc, above) and the average particle volume computed within the program.

Example 2: IDSTP = 1 (Log normal distribution)

Column 5

```
1    3    9    5    4    5    0    0    0    0    0    0

3.70000E-01 1.54000E+00 0.00500E-00 1.00000E-00

10.6000E+00 0.10000E-05 00.0000E+00 0.00000E-05 25.0000E+00 1.00000E-02

    1.9530     .468000     0.00000     1.87000     1.000000E-09

    0.15900     1.87000     1.000000E-09

    0.15600     1.87000     1.000000E-09
```

Remarks: The second card carries RBAR, SIGMA, RLO and RHI. If RLO and RHI are set to zero, the program itself will choose RLO and RHI. Particle number density will also be calculated from mass density and concentration.

Example 3: IDSTP = 3 (Deirmendjian's Model C)

Column 5

```
    2    1    0    3    100    5    0    0    0    0    0    0

10.6000E+00 0.10000E-05 00.0000E+00 0.00000E-05 25.0000E+00 1.00000E-02

    0.0000    .000000    0.00000    1.87000    1.0000000-09
75.00000+00 25.00000+00
   0.0000    .000000    0.15900    1.87000    1.0000000-09
```

Remarks: 100 values of radii will be used for 2 values of relative humidity with different growth factors. Particle density will be calculated from mass density and concentration. Since IW = 0, the aerosol component is considered to be pure water; i.e., EMA and CAYA will be set equal to the values for water.

Example 4: IDSTP = 5 (Modified gamma distribution)

Column 5

```
    1    2    9    5    40    1    0    0    0    0    0    0

.0278520+00 1.225490+01 4.000000+00 .6000000+01 .1000000+01

.7000000+00 .0000000-04 .0000000+00 1.000000+02 5.000000+00 1.000000-02

    1.3300    .000000    0.00000    1.00000    1.0000000+00

    1.4300    .000000    0.00000    1.00000    1.0000000-01
```

Remarks: This example sets NINDX = Z, and treats a mixture of two aerosol components having different refractive indices and mass concentrations.

Example 5: IDSTP = 7 (Power Law)

Column 5

```
   1    1    0    7    0    1    1    3    1    23   0    8
+6.000000+00
10.60000+00  .0000000+00  .0000000+00  .1000000+03  25.00000+00  1.000000-02
   0.0000    .000000   0.00000    0.00000    0.0000000+00
```

Remarks: The GHG analytic phase function will be constructed at eight Gauss-Legendre angles (IAPX = 8) for pure water (IW = 0). Scattering fractions (not computed), phase functions, cosines, a counter, and Legendre coefficients will be written on unit 23 for individual wavelengths only.

```
                    ********************************
                    ***                          ***
                    ***     PROGRAM AGAUSX       ***
                    ***                          ***
                    ********************************

INTEGER CONTROL PARAMETERS: NWAVE NINDX IW IDSTP NRADI IT IANG NCRDS ITOT NUNIT MQRTE IAPX
                             2     1    9    0    11   5    0    0     0    4    12345   0

AEROSOL PARAMETERS ARE

   RADIUS    RELATIVE NO.    RADIUS    RELATIVE NO.    RADIUS    RELATIVE NO.    RADIUS    RELATIVE NO.    RADIUS    RELATIVE NO.

1.000000-001  .000000     1.200000-001 2.000000-001 1.400000-001 4.000000-001 1.600000-001 6.000000-001 1.800000-001 8.000000-001
2.000000-001 1.000000+000 2.200000-001 8.000000-001 2.400000-001 6.000000-001 2.600000-001 4.000000-001 2.800000-001 2.000000-001
3.000000-001  .000000

NORMALIZATION FACTOR FOR SIZE DISTRIBUTION =   .9999988-001
AVERAGE NUMERICAL DRY VOLUME IS               3.769914-002 CUBIC MICROMETERS

          SIZE-INTERVALS USED ARE AS FOLLOWS

 INTERVAL NO.   1     RMIN =      .10000      RMAX =      .30000
INPUT PARAMETERS
      WAVE =     .106000+002 MICRONS
      DWAVE =    .100000-005 MICRONS
      RELHUM =   .000000     PERCENT
      DENSH =    .000000     PARTICLES/CC
      TEMP =     .250000+002 DEG C
      DELTA (CONVERGENCE CRITERION) =  .100000-001
RELATIVE HUMIDITY OPTION IN EFFECT FOR  2 VALUES
***  PARTICLE NUMBER DENSITY WILL BE CALCULATED FROM MASS DENSITY AND MASS CONCENTRATION  ***

RELATIVE HUMIDITY FOR THIS RUN =    .00  PERCENT.  WAVELENGTH =     10.600 MICRONS
INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 -  .075620I

MASS DENSITY OF WATER AT  25.00 DEG C IS:     1.00 GM/CC
 INDX=  1 M=   1.953000 K = -  .468000I.  MASS DENSITY = 1.870000 GROWTH FACTOR =    .0000. CONC =  1.00000-009  GM/CC


R(MICRONS)  DRY  RADIUS     N(R)       MIE  SIZE     Q (EXT)      Q(SCA)         Q(RADAR)

   .10000  1.00000-001   .00000      5.92753-002  3.76803-002  9.58810-006  1.43542-005
   .30000  3.00000-001  7.95059-008  1.77826-001  1.17142-001  7.84951-004  1.15695-003
   .20000  2.00000-001  1.00000+001  1.18551-001  7.63388-002  1.54047-004  2.29277-004
   .15000  1.50000-001  5.00001+000  8.89130-002  5.68193-002  4.86250-005  7.26187-005
   .25000  2.50000-001  5.00001+000  1.48188-001  9.63911-002  3.77213-004  5.58973-004
   .12500  1.25000-001  2.50000+000  7.40942-002  4.72113-002  2.34271-005  3.50339-005
   .17500  1.75000-001  7.50001+000  1.03732-001  6.65223-002  9.01846-005  1.34473-004
   .22500  2.25000-001  7.50001+000  1.33369-001  8.62883-002  2.47104-004  3.67018-004
```

```
 .27500  2.75000-001  2.50000+000  1.63007-001  1.06668-001  5.53216-004  8.17687-004
 .11250  1.12500-001  1.25000+000  6.66847-002  4.24372-002  1.53641-005  2.29894-005
 .13750  1.37500-001  3.75000+000  8.15036-002  5.20046-002  3.43153-005  5.12839-005
 .16250  1.62500-001  6.25001+000  9.63224-002  6.16578-002  6.70104-005  1.00000-004
 .18750  1.87500-001  8.75001+000  1.11141-001  7.14152-002  1.18920-004  1.77162-004
 .21250  2.12500-001  8.75001+000  1.25960-001  8.12957-002  1.96458-004  2.92106-004
 .23750  2.37500-001  6.25001+000  1.40779-001  9.13193-002  3.06998-004  4.55464-004
 .26250  2.62500-001  3.75000+000  1.55598-001  1.01507-001  4.58887-004  6.79152-004
 .28750  2.87500-001  1.25000+000  1.70417-001  1.11879-001  6.61463-004  9.76341-004
FOR COMPONENT NO.   1  INTERVAL NO.   1   17 RADII WERE USED.  CONTRIBUTION TO CTSUM = 1.082710-002
FOR COMPONENT NO.  1 :    VPF =  5.33832-010   MASS CONCENTRATION =  9.98266-010  GM/CC.  KEXT =      1.53581-001 PER KM


TOTAL NUMBER OF RADII USED WAS    17
ATTENUATION COEF. =  1.53581-004  SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL

 DISTRIBUTION  WAVELENGTH      REFRACTIVE          EXTINCTION X SECTION        SCATTERING X SECTION            ALBDO
     TYPE       (MICRONS)        INDEX                (SQ MICRONS)             (SQ MICRONS)
       0         10.6000
K(EXT) = 1.5358138-001; K(SCA) = 4.6128525-004; K(RAD) = 6.8411013-004 ALL PER KM


WAVENUMBER = 9.433962+002 CM-1     DENSITY = 1.418492+004 PARTICLES PER CC


                                  PHASE FUNCTION
                          (INTEGRAL NORMALIZED TO 4 PI OMEGA ZERO)

     MU         PHASE FUNCTION      MU         PHASE FUNCTION      MU         PHASE FUNCTION      MU         PHASE FUNCTION

  .906179860   .4146052001-002   .538469315   .2926897054-002   .000000000   .2252592763-002  -.538469315   .2884668502-002
 -.906179853   .4058968159-002

                        L                    L-TH COEFFICIENT                    RMS  DEVIATION

                        0          3.003523219376802-003                 7.750136210233904-004
                        1          4.436977906152606-005                 7.744139511487447-004
                        2          1.501870749052614-003                 2.744890281292101-006
                        3          6.654647222603671-006                 4.267161513027418-009


**********************************   END OF RELATIVE HUMIDITY CYCLE NUMBER   1   **********************************


RELATIVE HUMIDITY FOR THIS RUN =  75.00  PERCENT.  WAVELENGTH =     10.600 MICRONS
INDEX OF REFRACTION FOR PURE WATER IS:  1.178200 -  .075620I

MASS DENSITY OF WATER AT  25.00 DEG C IS:     1.00 GM/CC
 INDX=  1 M=   1.953000 K = -   .468000I.  MASS DENSITY = 1.870000 GROWTH FACTOR =    .1590. CONC =  1.00000-009  GM/CC


R(MICRONS)  DRY  RADIUS      N(R)        MIE  SIZE      Q (EXT)       Q(SCA)          Q(RADAR)
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12118	1.00000-001	.00000	7.18307-002	3.78534-002	9.96307-006	1.49079-005
36866	3.00000-001	7.45059-008	2.18525-001	1.19070-001	8.57504-004	1.25688-003
24492	2.00000-001	1.00000+001	1.45178-001	7.74352-002	1.66587-004	2.47350-004
18305	1.50000-001	5.00001+000	1.08504-001	5.74620-002	5.09194-005	7.74377-005
30679	2.50000-001	5.00001+000	1.81852-001	9.79190-002	4.80660-004	6.06222-004
15212	1.25000-001	2.50000+000	9.01675-002	4.76208-002	2.47475-005	3.69759-005
21399	1.75000-001	7.50001+000	1.26841-001	6.73942-002	9.70107-005	1.44390-004
27586	2.25000-001	7.50001+000	1.63515-001	8.76038-002	2.68255-004	3.97217-004
33773	2.75000-001	2.50000+000	2.00189-001	1.08401-001	6.03497-004	8.87871-004
13665	1.12500-001	1.25000+000	8.09991-002	4.27289-002	1.61124-005	2.40921-005
16758	1.37500-001	3.75000+000	9.93359-002	5.25311-002	3.64635-005	5.44353-005
19852	1.62500-001	6.25001+000	1.17673-001	6.24156-002	7.08390-005	1.07040-004
22945	1.87500-001	8.75001+000	1.36010-001	7.23999-002	1.28287-004	1.90719-004
26039	2.12500-001	8.75001+000	1.54346-001	8.25024-002	2.02894-004	3.15686-004
29132	2.37500-001	6.25001+000	1.72683-001	9.27418-002	3.33784-004	4.93512-004
32226	2.62500-001	3.75000+000	1.91020-001	1.03138-001	5.00128-004	7.37074-004
35319	2.87500-001	1.25000+000	2.09357-001	1.13711-001	7.22142-004	1.06049-003

FOR COMPONENT NO. 1 INTERVAL NO. 1 17 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.650363-002
FOR COMPONENT NO. 1 : VPF = 9.82639-010 MASS CONCENTRATION = 1.43246-009 GM/CC. KEXT = 2.34102-001 PER KM

TOTAL NUMBER OF RADII USED WAS 17
ATTENUATION COEF. = 2.34302-004 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL
ATTENUATION COEF. = 1.63426-004 SQ-METERS/MILLIGRAM OF WET AEROSOL MATERIAL

DISTRIBUTION TYPE	WAVELENGTH (MICRONS)	REFRACTIVE INDEX	EXTINCTION X SECTION (SQ MICRONS)	SCATTERING X SECTION (SQ MICRONS)	ALBDO
0	10.6000	1.5871(1 -.1781I)	1.65036087855697-002	5.31542978023936-005	3.22076815064065-003

K(EXT) = 2.34102431-001; K(SCA) = 7.5398964-004; K(RAD) = 1.1142163-003 ALL PER KM

WAVENUMBER = 9.433962+002 CM-1 DENSITY = 1.418492+004 PARTICLES PER CC

PHASE FUNCTION
(INTEGRAL NORMALIZED TO 4 PI OMEGA ZERO)

MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
.906179860	.4459963704-002	.538469315	.3144036687-002	.000000000	.2415478462-002	-.538469315	.3087851917-002
-.906179853	.4338685889-002						

L	L-TH COEFFICIENT	RMS DEVIATION
0	3.220767830498517-003	8.315518498420715-004
1	6.077715806895867-005	8.304896036861464-004
2	1.610604202141985-003	4.579665130677313-006
3	1.110328958020546-005	1.081949518866310-008
4	3.374043444637209-008	6.380313707921026-010

********** END OF RELATIVE HUMIDITY CYCLE NUMBER 2 **********
SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS :

WAVELENGTH (MICROMETERS)	REL.HUMIDITY (PERCENT)	AEROSOL MASS (GM/(SQ.CM-KM)	K(EXTINCTION) (PER KM)
10.600000	.000000	9.98266-005	1.53581-001
10.600000	75.000000	1.43246-004	2.34102-001

RESULTS AVERAGED OVER PARAMETER NWAVE FOLLOW

EXTINCTION COEF. = 9.93842-001 (PER KM)

SCATTERING COEF. = 6.07637-004 (PER KM)

BACK-SCATTERING COEF. = 8.99163-004 (PER KM)

ATTENUATION COEF. = 9.93842-004 SQ-METERS/MG

MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
.906179860	.4303007852-002	.538469315	.3035466856-002	.000000000	.2334035613-002	-.538469315	.2986260195-002
-.906179853	.4198827024-002						

L	L-TH COEFFICIENT	RMS DEVIATION
0	3.112145554041490-003	8.032697587623261-004
1	5.257347947917879-005	8.024513663258404-004
2	1.556237490149215-003	3.662256204961523-006
3	8.878974767867476-006	7.527153123021435-009
4	2.336128090973943-008	5.581565348800055-010

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                    ***     PROGRAM AGAUSX       ***
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INTEGER CONTROL PARAMETERS: NWAVE NINDX IW IDSTP NRADI IT IANG NCRDS ITOT NUNIT MQRTE IAPX
                             1     1    9    1   100   5    0    0     0    4       0    0


AEROSOL PARAMETERS ARE
                      RBAR=  .370000+000     SIGMA=  .154000+001 RLO =  .500000-002 RHI =  .100000+001

NORMALIZATION FACTOR FOR SIZE DISTRIBUTION =   .9893521+000

AVERAGE ANALYTIC DRY VOLUME PER PARTICLE IS    4.909649-001 CUBIC MICROMETERS
AVERAGE NUMERICAL DRY VOLUME IS                4.183917-001 CUBIC MICROMETERS

          SIZE-INTERVALS USED ARE AS FOLLOWS

 INTERVAL NO.   1     RMIN =      .00500      RMAX =      .37000
 INTERVAL NO.   2     RMIN =      .37000      RMAX =     1.00000
INPUT PARAMETERS
      WAVE =    .106000+002 MICRONS
      DWAVE =   .000000     MICRONS
      RELHUM =  .000000     PERCENT
      DENSH =   .000000     PARTICLES/CC
      TEMP =    .250000+002 DEG C
      DELTA (CONVERGENCE CRITERION) =  .100000-001
***  PARTICLE NUMBER DENSITY WILL BE CALCULATED FROM MASS DENSITY AND MASS CONCENTRATION  ***


RELATIVE HUMIDITY FOR THIS RUN =    .00  PERCENT.  WAVELENGTH =     10.600 MICRONS
INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 -  .075620I

MASS DENSITY OF WATER AT  25.00 DEG C IS:     1.00 GM/CC
 INDX=  1 M=   1.953000 K = -   .468000I.  MASS DENSITY = 1.870000 GROWTH FACTOR =    .0000. CONC =  1.00000-009  GM/CC

 FOR COMPONENT NO.   1  INTERVAL NO.   1   17 RADII WERE USED.  CONTRIBUTION TO CTSUM = 1.426828-002
 FOR COMPONENT NO.   1  INTERVAL NO.   2   17 RADII WERE USED.  CONTRIBUTION TO CTSUM = 1.294031-001
 FOR COMPONENT NO.  1 :    VPF =  5.34003-010   MASS CONCENTRATION =  9.98586-010  GM/CC.  KEXT =      1.83533-001 PER KM

 TOTAL NUMBER OF RADII USED WAS    34
 ATTENUATION COEF. =  1.83533-004  SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL

  DISTRIBUTION  WAVELENGTH     REFRACTIVE          EXTINCTION X SECTION        SCATTERING X SECTION            ALBDO
      TYPE      (MICRONS)        INDEX               (SQ MICRONS)                (SQ MICRONS)
        1        10.6000    1.9530(1 -.2396I)    1.4359458535909 7-001     9.1404756531119 3-003     6.3654737547040 0-002
 K(EXT) = 1.8353269-001; K(SCA) = 1.1682725-002; K(RAD) = 1.5537733-002 ALL PER KM


WAVENUMBER = 9.433962+002 CM-1     DENSITY = 1.278131+003 PARTICLES PER CC
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PHASE FUNCTION
(INTEGRAL NORMALIZED TO 4 PI OMEGA ZERO)

MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
.906179860	.9663867112-001	.538469315	.6619704887-001	.000000000	.4762377590-001	-.538469315	.5691573909-001
-.906179853	.7764094044-001						

L	L-TH COEFFICIENT	RMS DEVIATION
0	6.365473195910454-002	1.784613775089383-002
1	9.706226061098278-003	1.655639195814729-002
2	3.208455536514521-002	5.789812203147449-004
3	1.403631700668484-003	9.536886523164867-006
4	3.018663846887648-005	1.268959048950080-008

SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS :

WAVELENGTH (MICROMETERS)	REL.HUMIDITY (PERCENT)	AEROSOL MASS (GM/(SQ.CM-KM)	K(EXTINCTION) (PER KM)
10.600000	.000000	9.98586-005	1.83533-001

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                    ***     PROGRAM AGAUSX       ***
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INTEGER CONTROL PARAMETERS: NWAVE NINDX IW IDSTP NRADI IT IANG NCRDS ITOT NUNIT MQRIE IAPX
                             2     1    0   3   100   5   0    0     0    4      0    0

*** WATER ONLY CASE ***


AEROSOL PARAMETERS ARE

NORMALIZATION FACTOR FOR SIZE DISTRIBUTION =    .1135122+000
AVERAGE NUMERICAL DRY VOLUME IS                 1.197754-002 CUBIC MICROMETERS

          SIZE-INTERVALS USED ARE AS FOLLOWS

 INTERVAL NO.   1     RMIN =      .02000      RMAX =      .10000
 INTERVAL NO.   2     RMIN =      .10000      RMAX =     2.00000
INPUT PARAMETERS
      WAVE =     .106000+002 MICRONS
      DWAVE =    .100000-005 MICRONS
      RELHUM =   .000000     PERCENT
      DENSH =    .000000     PARTICLES/CC
      TEMP =     .250000+002 DEG C
      DELTA (CONVERGENCE CRITERION) =  .100000-001
RELATIVE HUMIDITY OPTION IN EFFECT FOR  2 VALUES
***  PARTICLE NUMBER DENSITY WILL BE CALCULATED FROM MASS DENSITY AND MASS CONCENTRATION  ***


RELATIVE HUMIDITY FOR THIS RUN =    .00  PERCENT.  WAVELENGTH =     10.600 MICRONS
INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 -  .0756201

MASS DENSITY OF WATER AT  25.00 DEG C IS:     1.00 GM/CC
 INDX=  1 M=   1.178200 K = -   .0756201.  MASS DENSITY = 1.870000 GROWTH FACTOR =    .0000. CONC =  1.00000-009  GM/CC

 FOR COMPONENT NO.   1  INTERVAL NO.   1   17 RADII WERE USED.  CONTRIBUTION TO CTSUM = 7.654085-005
 FOR COMPONENT NO.   1  INTERVAL NO.   2   65 RADII WERE USED.  CONTRIBUTION TO CTSUM = 9.724075-004
 FOR COMPONENT NO.  1 :    VPF =  1.61669-010   MASS CONCENTRATION =  3.02322-010  GM/CC.  KEXT =      1.41262-002 PER KM

 TOTAL NUMBER OF RADII USED WAS    82
 ATTENUATION COEF. =  4.57685-005  SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL

  DISTRIBUTION  WAVELENGTH     REFRACTIVE          EXTINCTION X SECTION        SCATTERING X SECTION            ALBDO
      TYPE      (MICRONS)        INDEX
        3        10.6000    1.1782(1 -.06421)     1.02512286684942-003     2.84846289559937-005     2.77865510433912-002
K(EXT) = 1.4126193-002; K(SCA) = 3.9251818-004; K(RAD) = 4.0384070-004 ALL PER KM


WAVENUMBER = 9.433962+002 CM-1      DENSITY = 1.378000+004 PARTICLES PER CC
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PHASE FUNCTION
(INTEGRAL NORMALIZED TO 4 PI OMEGA ZERO)

MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
.906179860	.5109181860-001	.538469315	.3195016971-001	.000000000	.2029759437-001	-.538469315	.2146602934-001
-.906179853	.2682040236-001						

L	L-TH COEFFICIENT	RMS DEVIATION
0	2.778654801659286-002	1.146680593956262-002
1	1.186961145140231-002	7.929413230158389-003
2	1.517573744058609-002	1.138761916081421-003
3	2.753715642029420-003	8.331048138643382-005
4	2.637724683154374-004	6.702934984836872-009

********** END OF RELATIVE HUMIDITY CYCLE NUMBER 1 **********

RELATIVE HUMIDITY FOR THIS RUN = 75.00 PERCENT. WAVELENGTH = 10.600 MICRONS
INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 - .075620I

MASS DENSITY OF WATER AT 25.00 DEG C IS: 1.00 GM/CC
INDX= 1 M= 1.178200 K = - .075620I. MASS DENSITY = 1.870000 GROWTH FACTOR = .1590. CONC = 1.00000-009 GM/CC

FOR COMPONENT NO. 1 INTERVAL NO. 1 17 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.327722-004
FOR COMPONENT NO. 1 INTERVAL NO. 2 65 RADII WERE USED. CONTRIBUTION TO CTSUM = 1.851981-003
FOR COMPONENT NO. 1 : VPF = 2.98743-010 MASS CONCENTRATION = 4.35500-010 GM/CC. KEXT = 2.67287-002 PER KM

TOTAL NUMBER OF RADII USED WAS 82
ATTENUATION COEF. = 8.66003-005 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL
ATTENUATION COEF. = 6.13747-005 SQ-METERS/MILLIGRAM OF WET AEROSOL MATERIAL

DISTRIBUTION TYPE	WAVELENGTH (MICRONS)	REFRACTIVE INDEX	EXTINCTION X SECTION (SQ MICRONS)	SCATTERING X SECTION (SQ MICRONS)	ALBDO
3	10.6000	1.1782(1 -.06421)	1.939672059961 59-003	8.68672477362 54-005	4447845021262765-002

K(EXT) = 2.672868I-002; K(SCA) = 1.1970307-003; K(RAD) = 9.9110602-004 ALL PER KM

WAVENUMBER = 9.433962+002 CM-1 DENSITY = 1.378000+004 PARTICLES PER CC

PHASE FUNCTION
(INTEGRAL NORMALIZED TO 4 PI OMEGA ZERO)

MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
.906179860	.9466039110-001	.538469315	.5532553978-001	.000000000	.3153885575-001	-.538469315	.3000225802-001
-.906179853	.3528082650-001						

L	L-TH COEFFICIENT	RMS DEVIATION

0	4.478449793532491-002	2.483143028803170-002
1	2.891276823356948-002	1.442674698773772-002
2	2.724765380844474-002	2.890899160140380-003
3	6.964836449240063-003	3.185206769558135-004
4	1.008492516120896-003	1.253139425561045-008

********** END OF RELATIVE HUMIDITY CYCLE NUMBER 2 **********

SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS :

WAVELENGTH (MICROMETERS)	REL.HUMIDITY (PERCENT)	AEROSOL MASS (GM/(SQ.CM-KM)	K(EXTINCTION) (PER KM)
10.600000	.000000	3.02322-005	1.41262-002
10.600000	75.000000	4.35500-005	2.67287-002

RESULTS AVERAGED OVER PARAMETER NWAVE FOLLOW

EXTINCTION COEF. = 2.04274-002 (PER KM)

SCATTERING COEF. = 7.94774-004 (PER KM)

BACK-SCATTERING COEF. = 6.97473-004 (PER KM)

ATTENUATION COEF. = 6.61844-005 SQ-METERS/MG

PHASE FUNCTION

MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
.906179860	.728761041 5-001						
-.906179853	.310506143 1-001						

L	L-TH COEFFICIENT	RMS DEVIATION
0	3.628552239388227-002	1.810604403726757-002
1	2.039118949323893-002	1.117380033247173-002
2	2.121169539168477-002	2.014147612499073-003
3	4.859276057686657-003	2.009153358812910-004
4	6.361324922181666-004	9.650542254213690-009

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                    ***    PROGRAM AGAUSX    ***
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INTEGER CONTROL PARAMETERS: NWAVE NINDX IW IDSTP NRADI IT IANG NCRDS ITOT NUNIT MQRTE IAPX


AEROSOL PARAMETERS ARE
                        RLO=  .2785-001 RHI=  .1225+002 RC=  .4000+001 ALF=  .6000+001 GAM=  .1000+001

NORMALIZATION FACTOR FOR SIZE DISTRIBUTION =   .4210611+002

AVERAGE ANALYTIC DRY VOLUME PER PARTICLE IS    6.255275+002 CUBIC MICROMETERS
AVERAGE NUMERICAL DRY VOLUME IS                6.182091+002 CUBIC MICROMETERS

           SIZE-INTERVALS USED ARE AS FOLLOWS

 INTERVAL NO.   1     RMIN =      .02785      RMAX =     4.00000
 INTERVAL NO.   2     RMIN =     4.00000      RMAX =    12.25490
INPUT PARAMETERS
      WAVE =    .700000+000 MICRONS
      DWAVE =   .000000     MICRONS
      RELHUM =  .000000     PERCENT
      DENSH =   .100000-008 PARTICLES/CC
      TEMP =    .500000+001 DEG C
      DELTA (CONVERGENCE CRITERION) =  .100000-001
LOOPING OPTION IN EFFECT FOR  2 AEROSOL COMPONENTS


RELATIVE HUMIDITY FOR THIS RUN =    .00  PERCENT.  WAVELENGTH =       .700 MICRONS
INDEX OF REFRACTION FOR PURE WATER IS: 1.330000 -  .0000001

MASS DENSITY OF WATER AT   5.00 DEG C IS:     1.00 GM/CC
 INDX=  1 M=   1.330000 K = -   .0000001.  MASS DENSITY = 1.000000 GROWTH FACTOR =    .0000. CONC =  1.00000+000  GM/CC

 FOR COMPONENT NO.   1  INTERVAL NO.   1   33 RADII WERE USED.  CONTRIBUTION TO CTSUM = 2.668850+001
 FOR COMPONENT NO.   1  INTERVAL NO.   2   17 RADII WERE USED.  CONTRIBUTION TO CTSUM = 1.405387+002
 FOR COMPONENT NO.  1 :    VPF =  6.17094-012   MASS CONCENTRATION =  6.17094-012  GM/CC.  KEXT =      1.67229-003 PER KM

         ****************************  END OF AEROSOL COMPONENT CYCLE NUMBER   1  ****************************


 INDX=  2 M=  1.430000 K = -   .0000001.  MASS DENSITY = 1.000000 GROWTH FACTOR =    .0000. CONC =  1.00000-001  GM/CC

 FOR COMPONENT NO.   2  INTERVAL NO.   1   33 RADII WERE USED.  CONTRIBUTION TO CTSUM = 2.668959+001
 FOR COMPONENT NO.   2  INTERVAL NO.   2   17 RADII WERE USED.  CONTRIBUTION TO CTSUM = 1.428248+002
 FOR COMPONENT NO.  2 :    VPF =  6.17094-012   MASS CONCENTRATION =  6.17094-012  GM/CC.  KEXT =      1.69517-003 PER KM

         ****************************  END OF AEROSOL COMPONENT CYCLE NUMBER   2  ****************************
```

TOTAL MASS CONCENTRATION = 1.23419-011 GM/CC; TOTAL KEXT = 3.36746-003 PER KM

TOTAL NUMBER OF RADII USED WAS 100
ATTENUATION COEF. = 2.72356-004 SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL

*** WARNING *** OPTIMAL PF EXPANSION ORDER OF 42 EXCEEDS INPUT IT = 1. PF VALUES SHOULD BE USED CAUTIOUSLY

THIS IS A MIXED CASE . SUBSEQUENT REFRACTIVE INDEX PRINT-OUTS ARE NOT GENERALLY VALID

DISTRIBUTION TYPE	WAVELENGTH (MICRONS)	REFRACTIVE INDEX	EXTINCTION X SECTION (SQ MICRONS)	SCATTERING X SECTION (SQ MICRONS)	ALBDO
5	.7000	1.4300(1 .00001)	1.68372949600220+002	1.68372949600220+002	1.00000000000000+000

K(EXT) = 3.3674590-003; K(SCA) = 3.3674590-003; K(RAD) = 4.9359845-003 ALL PER KM

WAVENUMBER = 1.428571+004 CM-1 DENSITY = 2.000000-002 PARTICLES PER CC

SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS :

WAVELENGTH (MICROMETERS)	REL.HUMIDITY (PERCENT)	AEROSOL MASS (GM/(SQ.CM-KM)	K(EXTINCTION) (PER KM)
.700000	.000000	1.23419-006	3.36746-003

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                    ***                            ***
                    ***      PROGRAM AGAUSX        ***
                    ***                            ***
                    **********************************

INTEGER CONTROL PARAMETERS: NWAVE NINDX IW IDSTP NRADI IT IANG NCRDS ITOT NUNIT MQRTE IAPX
                             1     1    0    7     0    1    0    3     1   23      0    8

*** WATER ONLY CASE ***


AEROSOL PARAMETERS ARE
                      RLO=  .1000+000 RHI=  .1500+002 CUE=  .3000+002 A=  .4000+001 VIS= .6000+001


NORMALIZATION FACTOR FOR SIZE DISTRIBUTION =   .1128782+005
AVERAGE NUMERICAL DRY VOLUME IS                5.599874-002 CUBIC MICROMETERS

          SIZE-INTERVALS USED ARE AS FOLLOWS

 INTERVAL NO.   1     RMIN =      .10000      RMAX =      .11892
 INTERVAL NO.   2     RMIN =      .11892      RMAX =    15.00000
INPUT PARAMETERS
      WAVE =    .106000+002 MICRONS
      DWAVE =   .000000     MICRONS
      RELHUM =  .000000     PERCENT
      DENSH =   .100000+003 PARTICLES/CC
      TEMP =    .250000+002 DEG C
      DELTA (CONVERGENCE CRITERION) =  .100000-001


RELATIVE HUMIDITY FOR TH
INDEX OF REFRACTION FOR PURE WATER IS: 1.178200 -  .075620I

MASS DENSITY OF WATER AT  25.00 DEG C IS:     1.00 GM/CC
 INDX=  1 M=   1.178200 K = -  .075620I.  MASS DENSITY = 1.000000 GROWTH FACTOR =    .0000. CONC =   .00000      GM/CC

 FOR COMPONENT NO.   1  INTERVAL NO.   1    9 RADII WERE USED.  CONTRIBUTION TO CTSUM = 1.600058-004

*** CONVERGENCE LEVEL NOT REACHED FOR INTERVAL NO.   2 ***

 FOR COMPONENT NO.   1  INTERVAL NO.   2  257 RADII WERE USED.  CONTRIBUTION TO CTSUM = 5.893135-003
 FOR COMPONENT NO.  1 :    VPF =  1.39527-009   MASS CONCENTRATION =  1.39527-009  GM/CC.  KEXT =      1.50820-001 PER KM

 TOTAL NUMBER OF RADII USED WAS   266

 OMEGA SUB-1 =  5.644456297059 2-001
 OMEGA SUB-2 =  7.419748668670 7-001

 ATTENUATION COEF. =  1.08063-004  SQ-METERS/MILLIGRAM OF DRY AEROSOL MATERIAL
  DISTRIBUTION  WAVELENGTH     REFRACTIVE          EXTINCTION X SECTION        SCATTERING X SECTION            ALBDO
      TYPE      (MICRONS)        INDEX                (SQ MICRONS)                (SQ MICRONS)
        7         10.6000    1.17821 -.06421     6.051396485418 08-003     1.451696531148 63-003     2639894464612 0
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K(EXT) = 1.5081969-001; K(SCA) = 3.6180810-002; K(RAD) = 3.9616963-003 ALL PER KM

WAVENUMBER = 9.433962+002 CM-1 DENSITY = 2.492312+004 PARTICLES PER CC

GHG PHASE FUNCTION FOR ASYMMETRY FACTOR (G) = .7843

COMPUTED PHASE FUNCTION AT ZERO DEGREES IS 5.2465

GHG PHASE FUNCTION AT ZERO DEGREES IS 3.7157

GHG VALUES

MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION	MU	PHASE FUNCTION
.960289866	.2677733749+001	.796666488	.6179881915+000	.525532417	.1655803137+000	.183434647	.4482690804-001
-.183434647	.4108893569-002	-.525532417	.2865489456-002	-.796666488	.2266309719-002	-.960289866	.1998729800-002

TRUE OMEGA0 = .2399 INTEGRATED GHG PHASE FUNCTION = 3.0146 AND PERCENT ERROR = .0000

GHG COEFFICIENTS

L	OMEGA	L	OMEGA	L	OMEGA	L	OMEGA
1	.239894+000	2	.598084+000	3	.723577+000	4	.676869+000
5	.569799+000	6	.447981+000	7	.306446+000	8	.153074+000

PERCENT ERRORS: OMEGA 0 = .000
OMEGA 1 = 5.960
OMEGA 2 = -2.414

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C                          PROGRAM AGAUSX                                  AGXM0100
C                                                                          AGXM0110
C          REVISION DATE  25  MAY,  1980                                   AGXM0120
C                                                                          AGXM0130
C          FOR OPERATIONAL QUESTIONS, OR POSSIBLE INACCURACIES,            AGXM0140
C          THAT YOU MAY HAVE OR FIND CONCERNING THIS PROGRAM,               AGXM0150
C          PLEASE CONTACT DR. R.C. SHIRKEY, ATMOSPHERIC SCIENCES LAB.,     AGXM0160
C          WSMR, N.M.  88002: PHONE (505) 678-4200 OR AUTOVON 278-4200.    AGXM0170
C                                                                          AGXM0180
C          A MAJORITY OF THE WORK FOUND HEREIN WAS PERFORMED AT NEW        AGXM0190
C          MEXICO STATE UNIVERSITY, DEPT OF PHYSICS, BY DR. A. MILLER.     AGXM0200
C          THANKS ARE ALSO DUE TO DR. R.B. GOMEZ (ASL) AND                 AGXM0210
C          DR. G.H. GOEDECKE (NMSU).                                       AGXM0220
C                                                                          AGXM0230
C     PURPOSE:                                                             AGXM0240
C             TO CALCULATE EXTINCTION COEFFICIENTS, ETC., AND PRODUCE      AGXM0250
C     LEGENDRE EXPANSION COEFFICIENTS/ PHASE FUNCTIONS/ SCATTERING         AGXM0260
C     FRACTIONS UNDER A WIDE VARIETY OF CONDITIONS AND AEROSOL             AGXM0270
C     DISTRIBUTIONS AT ONE OR MORE WAVELENGTHS.  THE PHASE FUNCTION        AGXM0280
C     IS NORMALIZED TO 4 PI OMEGA ZERO AND MAY BE RENORMALIZED BY          AGXM0290
C     DIVISION BY THE APPROPRIATE CONSTANT(S).                             AGXM0300
C                                                                          AGXM0310
C     **********************  INPUT  **************************           AGXM0320
C                                                                          AGXM0330
C     CARD 1 - INTEGER CONTROL PARAMETERS: NWAVE, NINDX, IW, IDSTP,        AGXM0340
C              NRADI, IT, IANG, NCRDS, ITOT, NUNIT, MQRTE, IAPX            AGXM0350
C              FORMAT (12I5)                                               AGXM0360
C   NWAVE: IS THE NO. OF WAVELENGTHS, OR REL. HUMIDITY VALUES TO BE        AGXM0370
C     TREATED IN THIS RUN. SEE COMMENTS CIRCA READ OF WAVE, DWAVE, ETC.    AGXM0380
C     N.B. NWAVE MUST BE .LE. 5                                            AGXM0390
C   NINDX: IS THE NBR OF AEROSOL COMPONENTS WHICH WILL HAVE DIFFERENT      AGXM0400
C     OPTICAL CONSTANTS, MASS DENSITIES OR MASS CONCENTRATIONS.            AGXM0410
C   IW: =0 WILL SET THE REFRACTIVE INDEX OF THE DRY AEROSOL EQUAL          AGXM0420
C     TO THAT OF WATER AT THE INPUT WAVELENGTH AND TEMP.  IF IW.NE.0       AGXM0430
C     AND HANELS' GROWTH FACTOR IS ZERO (EMUA=0 -CARD 4), THEN THE         AGXM0440
C     INPUT REFRACTIVE INDEX (EMA,CAYA) WILL BE USED FOR THE AEROSOL.      AGXM0450
C     OTHERWISE THE REFRACTIVE INDEX IS ADJUSTED PER HANEL (SEE BELOW).    AGXM0460
C   IDSTP: IDENTIFIES TYPE OF AEROSOL SIZE DISTRIBUTION TO BE USED.        AGXM0470
C   NRADI: NO. OF PARTICLE RADII TO BE EXPECTED FOR IDSTP=0 OR 3:          AGXM0480
C     THE INPUT VALUE OF NRADI IS IGNORED FOR IDSTP NOT ZERO OR 3.         AGXM0490
C     NRADI MUST BE LESS THAN 513.                                         AGXM0500
C   IT: IS THE NUMBER OF GAUSS-LEGENDRE ANGLES (ORDER OF EXPANSION)        AGXM0510
C     IF IANG=0 OR NBR OF ANGLES BETWEEN 0 DEG AND 180 DEG IF IANG =1.     AGXM0520
C     IF ONLY EXTINCION COEFFICIENTS, ETC. ARE DESIRED, I.E. NOT PHASE     AGXM0530
C     FUNCTIONS, THEN SET -IT- EQUAL TO ONE.                               AGXM0540
C   IANG:= 0 FOR COMPUTATIONS OF PHASE FN. AT -IT- GAUSS-LEGENDRE          AGXM0550
C     QUADRATURE ANGLES: NO SCATTERING FRACTIONS WILL BE PRINTED.          AGXM0560
C     IANG=1 FOR COMPUTATIONS OF SCATTERING FRACTIONS AND PHASE            AGXM0570
C     FUNCTIONS AT -IT- EQUALLY SPACED ANGLES BETWEEN 0 AND 180 DEG.       AGXM0580
C     IANG=2 WILL ALLOW -IT- USER SUPPLIED ANGLES TO BE READ -             AGXM0590
C     FORMAT (16F5.1). THIS REQUIRES AT LEAST ONE CARD OF TYPE IA.         AGXM0600
C   NCRDS: =1 WRITE/PUNCH LEGENDRE COEFFICIENTS AND ORDER OF EXPANSION     AGXM0610
C     ON NUNIT - FORMAT (E25.14,1X,I5):                                    AGXM0620
C     =2 WRITE/PUNCH SCATTERING FRACTIONS, PHASE FUNCTIONS, COSINES AND    AGXM0630
C     COUNTER ON NUNIT - FORMAT (3(E12.6,1X),I5):                          AGXM0640
C     =3 WRITE/PUNCH BOTH SCATTERING FRACTIONS, PHASE FUNCTIONS,           AGXM0650
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C      COSINES, COUNTER, AND LEGENDRE COEFFICIENTS AND ORDER OF EXPANSION AGXM0660
C      ON NUNIT - FORMATS (3(E12.6,1X),I5) AND (E25.14,1X,I5):          AGXM0670
C      SCATTERING FRACTIONS, PHASE FUNCTIONS, COSINES, AND COUNTER      AGXM0680
C      (RESPECTIVELY) ARE ALWAYS WRITTEN/PUNCHED BEFORE THE LEGENDRE    AGXM0690
C      COEFFICIENTS AND ORDER OF EXPANSION (RESPECTIVELY).              AGXM0700
C    ITOT: WORKS IN CONJUNCTION WITH NCRDS AND NWAVE TO WRITE/PUNCH     AGXM0710
C      EITHER INDIVIDUAL WAVELENGTH VALUES OR AVERAGED WAVELENGTH VALUES AGXM0720
C      OR BOTH ON NUNIT: =1 FOR INDIVIDUAL WAVELENGTHS; =2 FOR AVERAGED AGXM0730
C      WAVELENGTHS; =3 FOR BOTH.                                        AGXM0740
C   NUNIT: DEFINES DEVICE NUMBER..SEE PREVIOUS COMMENT CARD.            AGXM0750
C   MQRTE:=12345 WILL CAUSE PRINTS OF MIE EFFICIENCY FACTORS AT         AGXM0760
C      EVERY VALUE OF PARTICLE RADIUS USED IN THE MIE CALCULATIONS;     AGXM0770
C      SET MQRTE = 0 IF SUCH PRINTS ARE NOT DESIRED.                    AGXM0780
C   IAPX: IF .GT. ZERO THE GHG (ANALYTIC) PHASE FUNCTION WILL BE        AGXM0790
C      CONSTRUCTED AT IAPX GAUSS-LEGENDRE ANGLES (ORDER OF EXPANSION).  AGXM0800
C                                                                       AGXM0810
C      CARD 1A - USER SUPPLIED SET OF -IT- ANGLES  FORMAT (16F5.1)      AGXM0820
C                16 VALUES PER CARD, MORE THAN 1 CARD MAY BE NEEDED.    AGXM0830
C                THIS CARD IS ONLY NEEDED WHEN IANG=2.                  AGXM0840
C                                                                       AGXM0850
C      CARD 2 - DISTRIBUTION PARAMETERS: ONLY ONE TYPE PER RUN.         AGXM0860
C                FORMAT (6E12.6) - READ IN AGXPT1 - ALL UNITS IN MICRONS AGXM0870
C       TYPE 0. USER SUPPLIED - NRADI+1 CARDS                           AGXM0880
C                RLO, DELLR                                             AGXM0890
C                FF(I), I = 1, NRADI                                    AGXM0900
C       TYPE 1. LOG-NORMAL                                              AGXM0910
C                RBAR, SIGMA, RLO, RHI                                  AGXM0920
C       TYPE 2. DOUBLE EXPONENTIAL                                      AGXM0930
C                RLO, RHI, CUE, A, B                                    AGXM0940
C       TYPE 3. DEIRMENDJIAN MODEL C                                    AGXM0950
C                - NO INPUT -                                           AGXM0960
C       TYPE 4. POWER LAW (JUNGE)                                       AGXM0970
C                RLO, RHI, CUE, A                                       AGXM0980
C       TYPE 5. MODIFIED GAMMA                                          AGXM0990
C                RLO, RHI, RC, ALF, GAM                                 AGXM1000
C       TYPE 6. MODIFIED GAMMA FOG MODEL                                AGXM1010
C                RLO, RHI, RC, ALF, GAM, ELWC                           AGXM1020
C       TYPE 7. POWER LAW                                               AGXM1030
C                VIS                                                    AGXM1040
C       TYPE 8. CONTINENTAL BIMODAL                                     AGXM1050
C                - NO INPUT -                                           AGXM1060
C       TYPE 9. MARITIME BIMODAL                                        AGXM1070
C                - NO INPUT -                                           AGXM1080
C       TYPE 10.URBAN BIMODAL                                           AGXM1090
C                - NO INPUT -                                           AGXM1100
C       TYPE 11.USER SUPPLIED BIMODAL                                   AGXM1110
C                FOA, RBARA, SGA, FOC, RBARC, SGL                       AGXM1120
C       TYPE 12.MARSHALL-PALMER RAIN MODEL                              AGXM1130
C                RAIN                                                   AGXM1140
C                                                                       AGXM1150
C      CARD 3 - CONTROL PARAMETERS: FORMAT (6E12.6)                     AGXM1160
C                WAVE, DWAVE, RELHUM, DENSH, TEMP, DELTA                AGXM1170
C                FOR LOOPING OVER RELATIVE HUMIDITY ADD                 AGXM1180
C                NWAVE-1 CARDS CONTAINING RELHUM,TEMP - FORMAT(2E12.6)  AGXM1190
C                SEE DWAVE BELOW.                                       AGXM1200
C   WAVE: IS WAVELENGTH IN MICROMETERS.                                 AGXM1210
C   DWAVE: IS THE WAVELENGTH INCREMENT IN MICROMETERS. IF DWAVE IS      AGXM1220
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C      LESS THAN 1.E-4, A SPECIAL CASE APPLIES USED FOR LOOPING OVER      AGXM1230
C       NWAVE VALUES OF RELHUM. THE FIRST TIME THIS CARD IS READ IT MUST  AGXM1240
C      CONTAIN: WAVE,DWAVE,RELHUM,DENSH,TEMP,AND DELTA: THE SECOND AND    AGXM1250
C      SUBSEQUENT  TIMES IT MUST ONLY HAVE  RELHUM AND TEMP ON IT.        AGXM1260
C       THIS REQUIRES REPETITION OF CARD 4.                               AGXM1270
C    RELHUM: IS RELATIVE HUMIDITY IN PERCENT.                             AGXM1280
C    DENSH: IS PARTICLE NUMBER PER CUBIC CENTIMETER.                      AGXM1290
C      USER-SUPPLIED VALUE OF DENSH WILL BE IGNORED FOR IDSTP=3 OR GT 6   AGXM1300
C      BECAUSE THOSE DISTRIBUTIONS CARRY PRE-DETERMINED DENSITY VALUES.   AGXM1310
C      ALSO, IF DENSH IS LESS THAN 1E-4, THE PARTICLE NUMBER DENSITY      AGXM1320
C      WILL BE CALCULATED FROM MASS DENSITY AND MASS CONCENTRATION.       AGXM1330
C    TEMP: IS THE TEMPERATURE OF THE ATMOSPHERE IN DEGREES C.             AGXM1340
C    DELTA:  IS THE CONVERGENCE CRITERION WITHIN A PARTICULAR SIZE       AGXM1350
C      RANGE INTERVAL: HALVING IS TERMINATED WHEN THE QUANTITY DEL       AGXM1360
C      IS LESS THAN DELTA.                                               AGXM1370
C                                                                        AGXM1380
C      CARD 4 -  OPTICAL AND PHYSICAL DATA (READ IN AGXPT2)              AGXM1390
C                FORMAT (4F10.5,E15.7)                                   AGXM1400
C                EMA, CAYA, EMUA, RHOA, CONC                             AGXM1410
C      REPEAT (NWAVE*NINDX) TIMES: IF IDSTP=6 THIS CARD IS NOT NEEDED.   AGXM1420
C    EMA: IS THE REAL PART OF THE INDEX OF REFRACTION OF DRY AEROSOL.     AGXM1430
C    CAYA: IS THE IMAGINARY PART OF REFRACTIVE INDEX FOR DRY AEROSOL.     AGXM1440
C      ***** CAYA IS ASSUMED TO BE NEGATIVE  ****                        AGXM1450
C      **** DO NOT ENTER CAYA WITH A NEGATIVE SIGN !!!!! *****           AGXM1460
C    EMUA:  IS HANEL'S GROWTH FACTOR (MU-BAR)/ACCRETION COEF.            AGXM1470
C    RHOA:  IS THE MASS DENSITY(SP. GRAV) OF DRY AEROSOL.                AGXM1480
C    CONC:  IS THE MASS CONCENTRATION(GM/CC) OF DRY AEROSOL.             AGXM1490
C                                                                        AGXM1500
C      **********************  END INPUT  **********************         AGXM1510
C                                                                        AGXM1520
C      REL. HUMIDITY TREATMENT PER G. HANEL/1976 ADV. IN GEOPHYS.        AGXM1530
C      USAGE REQUIRES AGAUSX,AGXPT1,AGXPT2,AGXPT3,GAUS,GUSET,ANGLE,      AGXM1540
C      MIEGX,WATER: FOR ANALYTIC PHASE FUNCTION CALCULATION              AGXM1550
C      INCLUDE GPHASX,GUSSTX,PRINTX.                                     AGXM1560
C                                                                        AGXM1570
       REAL KEXTT,KSCAT,KBAKT                                           AGXM1580
       DIMENSION F(513),R(513),C(100),PSUM(800),PSUMT(100),RR(9),DR(8)  AGXM1590
       DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100),OUT(5,4)   AGXM1600
       DIMENSION SCAT(100),SCATT(100),OLT(100)                          AGXM1610
       COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,IT,ITT,NRADI       AGXM1620
       COMMON /BK3/F,R,PSUM,SCAT,RR,DR,WAVE,EM,CAY,EMM,PI,IDSTP,        AGXM1630
      1        MQRTE,NKG,NHALV,NI                                       AGXM1640
C      PRINT OUT HEADING                                                 AGXM1650
       WRITE (6,100)                                                    AGXM1660
C      ***** READ INTEGER CONTROL PARAMETERS FOR THIS RUN  *****         AGXM1670
       READ (5,103) NWAVE,NINDX,IW,IDSTP,NRADI,IT,IANG,NCRDS,ITOT,      AGXM1680
      1     NUNIT,MQRTE,IAPX                                           AGXM1690
       IF (IDSTP.GT.12) GO TO 1                                         AGXM1700
       IF (IT.LE.1) IT=1                                                AGXM1710
       IF (NWAVE.EQ.0) NWAVE=1                                          AGXM1720
       IF (NUNIT.EQ.0) NUNIT=4                                          AGXM1730
       IF (IAPX.GT.0) IT=1                                              AGXM1740
       IF (IAPX.GT.0) IANG=0                                            AGXM1750
       IF (IDSTP.EQ.12) IW=1                                            AGXM1760
       IF (NINDX.LT.1.OR.IDSTP.EQ.6.OR.IDSTP.EQ.12) NINDX=1             AGXM1770
       WRITE (6,104) NWAVE,NINDX,IW,IDSTP,NRADI,IT,IANG,NCRDS,ITOT,     AGXM1780
      1     NUNIT,MQRTE,IAPX                                           AGXM1790
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      IF (IW.EQ.0) WRITE (6,122)                                        AGXM1800
C     INITIALIZE QUANTITIES USED IN SUMMATIONS                          AGXM1810
      DO 2 I=1,IT                                                       AGXM1820
      OLT(I)=0.E0                                                       AGXM1830
      OL(I)=0.E0                                                        AGXM1840
      PSUM(I)=0.E0                                                      AGXM1850
      SCATT(I)=0.E0                                                     AGXM1860
    2 PSUMT(I)=0.E0                                                     AGXM1870
      KEXTT=0.E0                                                        AGXM1880
      KSCAT=0.E0                                                        AGXM1890
      KBAKT=0.E0                                                        AGXM1900
      CATTN=0.E0                                                        AGXM1910
      ITT=IT-1                                                          AGXM1920
      PI=3.1415926535898E+00                                            AGXM1930
      IF((IANG.EQ.1).OR.(IANG.EQ.2)) GO TO 3                            AGXM1940
C     WHEN IANG=0, ROUTINE GUSET IS CALLED TO SET-UP THE ABSCISSAE AND  AGXM1950
C     WEIGHTS USED FOR CALCULATING THE PHASE-FUNCTION AT -IT- POINTS    AGXM1960
C     USED FOR NUMERICAL INTEGRATION VIA GAUSS-LEGENDRE QUADRATURE AND  AGXM1970
C     TO GET THE PHASE FUNCTION EXPANSION COEFS, OL( ).                 AGXM1980
C     THE WEIGHTS ARE PLACED IN THE ARRAY H(), AND THE COSINES OF THE   AGXM1990
C     ANGLES ARE PLACED IN THE ARRAY C().                               AGXM2000
      CALL GUSET(SCATT,F,PI)                                            AGXM2010
      IF (ITT.LT.3) ITT=3                                               AGXM2020
      GO TO 7                                                           AGXM2030
    3 CALL ANGLE(PI,IANG)                                               AGXM2040
C     SUBROUTINE ANGLE IS CALLED WHEN IANG=1 OR 2 TO SET-UP THE ANGLES  AGXM2050
C     AT WHICH PHASE FUNCTIONS AND SCATTERING FRACTIONS WILL BE         AGXM2060
C     CALCULATED.  ANGLES GO INTO ARRAY H() AND COSINES IN C().         AGXM2070
    7 CONTINUE                                                          AGXM2080
C     DETERMINE DETAILS OF AEROSOL SIZE-DISTRIBUTION VIA AGXPTI         AGXM2090
      CALL AGXPTI(DENS,FSUM,VOL,NRADI)                                  AGXM2100
      IF (IDSTP.EQ.6.OR.IDSTP.EQ.12) ELWC=DENS                          AGXM2110
C     DRYVOL IS THE AVERAGE VOLUME OF THE DRY AEROSOL PARTICLES IN      AGXM2120
C     CUBIC MICROMETERS.                                                AGXM2130
      DRYVOL=VOL                                                        AGXM2140
C     *** READ INPUT PARAMETERS ***                                     AGXM2150
      READ (5,105) WAVE,DWAVE,RELHUM,DENSH,TEMP,DELTA                   AGXM2160
      IF (NWAVE.EQ.1) DWAVE=0.E0                                        AGXM2170
      WRITE (6,106) WAVE,DWAVE,RELHUM,DENSH,TEMP,DELTA                  AGXM2180
      IF (NINDX.GT.1) WRITE (6,107) NINDX                               AGXM2190
      IF ((DWAVE.LT.1E-04).AND.(NWAVE.GT.1)) WRITE (6,108) NWAVE        AGXM2200
      IF ((DWAVE.GE.1E-04).AND.(NWAVE.GT.1)) WRITE (6,109) NWAVE        AGXM2210
      IF (DENSH.LT.1E-09) WRITE (6,110)                                 AGXM2220
      ENWAV=FLOAT(NWAVE)                                                AGXM2230
      IF (DWAVE.LT.1.E-4) GO TO 8                                       AGXM2240
      WAVE=WAVE-DWAVE                                                   AGXM2250
    8 DO 9 NWV=1,NWAVE                                                  AGXM2260
      IF (DWAVE.GT.1.E-4) GO TO 10                                      AGXM2270
      IF (NWV.EQ.1) GO TO 11                                            AGXM2280
      READ (5,105) RELHUM,TEMP                                          AGXM2290
      GO TO 11                                                          AGXM2300
   10 WAVE=WAVE+DWAVE                                                   AGXM2310
   11 VOL=DRYVOL                                                        AGXM2320
C     DETERMINE WHETHER THE USER SUPPLIED PARTICLE NUMBER DENSITY DENSH AGXM2330
C     SHOULD BE OVERIDDEN BECAUSE THE CHOSEN IDSTP CASE HAS FIXED       AGXM2340
C     PARAMETERS, AND/OR IF NUMBER DENSITIES ARE TO BE CALCULATED LATER AGXM2350
C     FROM THE AVG PARTICLE VOLUME, MASS DENSITY, AND MASS CONCENTRATIONAGXM2360
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      LLLL=0                                                            AGXM2370
      IF (IDSTP.EQ.6) GO TO 12                                          AGXM2380
      IF (IDSTP.EQ.3.OR.IDSTP.GE.7) LLLL=1                              AGXM2390
      IF (LLLL.EQ.1) GO TO 12                                           AGXM2400
      IF (DENSH.LE.1.E-4) GO TO 12                                      AGXM2410
      LLLL=1                                                            AGXM2420
      DENS=DENSH                                                        AGXM2430
   12 CONTINUE                                                          AGXM2440
C     RESTRICT RELATIVE HUMIDITY TO MAX OF 99 PERCENT.                  AGXM2450
      IF (RELHUM.GE.99.E+00) RELHUM=99.0E+000                           AGXM2460
      WRITE (6,111) RELHUM,WAVE                                         AGXM2470
      IF (DENS.EQ.0.0) DENS=1.0E+00                                     AGXM2480
      GNU=1.0E+04/WAVE                                                  AGXM2490
      IF (IDSTP.EQ.6.OR.IDSTP.EQ.12) DENS=ELWC                          AGXM2500
C     DENS IS USED AS AN ALIAS TO PASS ELWC TO ROUTINE AGXPT2.          AGXM2510
      CALL AGXPT2(RELHUM,CTSUM,CSSUM,CRSUM,VOL,TMASS,DENS,QATTN,TEMP,   AGXM2520
     1     DELTA,NINDX,IAPX,IW)                                         AGXM2530
      IF (IANG.NE.0) GO TO 13                                           AGXM2540
      AMAX=2.E+0*PI*EMM*R(NRADI)/WAVE                                   AGXM2550
      LMAX=3*IFIX(AMAX)                                                 AGXM2560
      IF ((LMAX.GT.IT).AND.(IAPX.EQ.0)) WRITE (6,112) LMAX,IT           AGXM2570
   13 CALL AGXPT3(CTSUM,CSSUM,CRSUM,GNU,DENS,NINDX,NUNIT,IANG,ITOT,IAPX)AGXM2580
C     SUM QUANTITIES OVER INDEX NWV.                                    AGXM2590
      DO 14 IK=1,IT                                                     AGXM2600
      OLT(IK)=OLT(IK)+OL(IK)                                            AGXM2610
      SCATT(IK)=SCAT(IK)+SCATT(IK)                                      AGXM2620
   14 PSUMT(IK)=PSUMT(IK)+PSUM(IK)                                      AGXM2630
C     KEXTT BECOMES THE TOTAL EXTINCTION COEF. (PER KILOMETER)          AGXM2640
C     KSCAT BECOMES THE TOTAL SCATTERING COEF. (PER KM)                 AGXM2650
C     KBAKT BECOMES THE TOTAL BACK-SCATTERING(RADAR) COEF (PER KM)      AGXM2660
C     ARRAY OUT(,) HOLDS SOME QUANTITIES FOR LATER PRINTOUTS            AGXM2670
      KEXTT=KEXTT+CTSUM                                                 AGXM2680
      KSCAT=KSCAT+CSSUM                                                 AGXM2690
      KBAKT=KBAKT+CRSUM                                                 AGXM2700
      CATTN=CATTN+QATTN                                                 AGXM2710
      OUT(NWV,1)=WAVE                                                   AGXM2720
      OUT(NWV,2)=RELHUM                                                 AGXM2730
      OUT(NWV,3)=TMASS*1.E5                                             AGXM2740
      OUT(NWV,4)=CTSUM                                                  AGXM2750
C     GPHASX WILL CONSTRUCT THE GHG ANALYTIC PHASE FUNCTION AT          AGXM2760
C     IAPX ANGLES.                                                      AGXM2770
      IF (IAPX.GT.0) CALL GPHASX(PSUM,PL,OL,RMS,PC,H,SCAT,SCATT,OLT,PI, AGXM2780
     +NUNIT,IAPX,NCRDS)                                                 AGXM2790
      IF ((NWAVE.GT.1).AND.(DWAVE.GE.1.E-04)) WRITE (6,113) NWV         AGXM2800
      IF ((NWAVE.GT.1).AND.(DWAVE.LT.1.E-04)) WRITE (6,114) NWV         AGXM2810
    9 CONTINUE                                                          AGXM2820
C     END OF NWAVE LOOP                                                 AGXM2830
      IF (IAPX.GT.0) GO TO 20                                           AGXM2840
      IF (NWAVE.EQ.1) GO TO 15                                          AGXM2850
C     DIVIDE BY NBR OF VALUES OF NWV TO GET AVERAGED RESULTS.           AGXM2860
      DO 16 I=1,IT                                                      AGXM2870
      OL(I)=OLT(I)/ENWAV                                                AGXM2880
      SCATT(I)=SCATT(I)/ENWAV                                           AGXM2890
      PSUM(I)=PSUMT(I)/ENWAV                                            AGXM2900
      IF (((NCRDS.EQ.2).OR.(NCRDS.EQ.3)).AND.((ITOT.EQ.2).OR.(ITOT.EQ.3 AGXM2910
     + ))) WRITE (NUNIT,115) SCATT(I),PSUM(I),C(I),I                    AGXM2920
   16 CONTINUE                                                          AGXM2930
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```
      IF (IANG.NE.0) GO TO 21                                          AGXM2940
      DO 17 I=1,IT                                                     AGXM2950
      II=I-1                                                           AGXM2960
      IF (((NCRDS.EQ.1).OR.(NCRDS.EQ.3)).AND.((ITOT.EQ.2).OR.(ITOT.EQ.3 AGXM2970
     + )) WRITE (NUNIT,116) OL(I),II                                   AGXM2980
   17 CONTINUE                                                         AGXM2990
   21 KEXTT=KEXTT/ENWAV                                                AGXM3000
      KSCAT=KSCAT/ENWAV                                                AGXM3010
      KBAKT=KBAKT/ENWAV                                                AGXM3020
      CATTN=CATTN/ENWAV                                                AGXM3030
   15 WRITE (6,117)                                                    AGXM3040
      WRITE (6,118)                                                    AGXM3050
      DO 18 J=1,NWAVE                                                  AGXM3060
   18 WRITE (6,119) (OUT(J,JJ),JJ=1,4)                                 AGXM3070
      IF (NWAVE.NE.1) CALL AGXPRT(SCATT,KEXTT,KSCAT,KBAKT,CATTN,IANG,  AGXM3080
     +     ITOT,NUNIT)                                                 AGXM3090
20    CONTINUE                                                         AGXM3100
      GO TO 19                                                         AGXM3110
    1 WRITE (6,120) IDSTP                                              AGXM3120
   19 STOP                                                             AGXM3130
  100 FORMAT (1H1,40X,30(1H*)/,1X,40X,3H***,24X,3H***/,1X,             AGXM3140
     +40X,30H***     PROGRAM AGAUSX     ***/,1X,40X,3H***,24X,3H***/   AGXM3150
     +,1X,40X,30(1H*)//)                                               AGXM3160
  103 FORMAT (12I5)                                                    AGXM3170
  104 FORMAT(1H ,90HINTEGER CONTROL PARAMETERS: NWAVE NINDX IW IDSTP NRAAGXM3180
     +DI IT IANG NCRDS ITOT NUNIT MQRTE IAPX/,1X,29X,2(I2,4X),I1,3X,I2, AGXM3190
     +3X,I3,2X,I2,3X,I1,4X,I1,5X,I1,3X,I2,3X,I5,2X,I2)                 AGXM3200
  105 FORMAT (6E12.6)                                                  AGXM3210
  106 FORMAT(1HO,16HINPUT PARAMETERS/,1X,6X,9HWAVE =   ,E12.6,8H MICRONSAGXM3220
     +/,1X,6X,9HDWAVE =  ,E12.6,8H MICRONS/,1X,6X,9HRELHUM = ,E12.6,   AGXM3230
     +8H PERCENT/,1X,6X,9HDENSH =  ,E12.6,13H PARTICLES/CC/,1X,6X,     AGXM3240
     +9HTEMP =   ,E12.6,6H DEG C/,1X,6X,19HDELTA (CONVERGENCE ,        AGXM3250
     +13HCRITERION) = ,E12.6)                                          AGXM3260
  107 FORMAT (1HO,29HLOOPING OPTION IN EFFECT FOR ,I2,                 AGXM3270
     +19H AEROSOL COMPONENTS)                                          AGXM3280
  108 FORMAT (1HO,39HRELATIVE HUMIDITY OPTION IN EFFECT FOR ,I2,       AGXM3290
     +7H VALUES)                                                       AGXM3300
  109 FORMAT (1HO,40HWAVELENGTH LOOPING OPTION IN EFFECT FOR ,I2,      AGXM3310
     +12H WAVELENGTHS)                                                 AGXM3320
  110 FORMAT(1HO,52H***  PARTICLE NUMBER DENSITY WILL BE CALCULATED FROMAGXM3330
     +,41H MASS DENSITY AND MASS CONCENTRATION  ***)                   AGXM3340
  111 FORMAT (1H1,//,1X,33HRELATIVE HUMIDITY FOR THIS RUN = ,F6.2,     AGXM3350
     +25H  PERCENT.  WAVELENGTH = ,F10.3,8H MICRONS)                   AGXM3360
  112 FORMAT (/49H *** WARNING *** OPTIMAL PF EXPANSION ORDER OF   ,I3, AGXM3370
     +        22H   EXCEEDS INPUT IT = ,I3,24H.   PF VALUES SHOULD BE , AGXM3380
     +        15HUSED CAUTIOUSLY/)                                     AGXM3390
  113 FORMAT (1HO//,1X,40(1H*),3X,31HEND OF WAVELENGTH CYCLE NUMBER ,I3,AGXM3400
     +3X,40(1H*))                                                      AGXM3410
  114 FORMAT (1HO//,1X,40(1H*),3X,38HEND OF RELATIVE HUMIDITY CYCLE NUMBAGXM3420
     +ER ,I3,3X,40(1H*))                                               AGXM3430
  115 FORMAT (3(E12.6,1X),I5)                                          AGXM3440
  116 FORMAT (E25.14,1X,I5)                                            AGXM3450
  117 FORMAT(1H1,49H SUMMARY OF RESULTS FOR THIS RUN ARE AS FOLLOWS :///)AGXM3460
  118 FORMAT(1H ,4X,48HWAVELENGTH    REL.HUMIDITY    AEROSOL MASS    K(,AGXM3470
     +  11HEXTINCTION),/1X,29H  (MICROMETERS)    (PERCENT)             AGXM3480
     +        ,6H   (GM,25H/(SQ.CM-KM)      (PER KM)/)                AGXM3490
  119 FORMAT (2F15.6,1P3E16.5)                                         AGXM3500
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 920 FORMAT (//13H *** IDSTP = ,I5,35H IS ILLEGAL. EXECUTION TERMINATED  AGXM3500
     +        2H* //)                                                    AGXM3510
 922 FORMAT (/,1X,23H*** WATER ONLY CASE ***/)                           AGXM3520
     END                                                                 AGXM3530
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      SUBROUTINE AGXPTI(DENS,FSUM,VOL,NRADI)                            PT100100
      DIMENSION F(513),R(513),PSUM(100),DR(8),RR(9),FF(514),SCAT(100)   PT100110
      COMMON /BK3/F,R,PSUM,SCAT,RR,DR,WAVE,EM,CAY,EMM,PI,IDSTP,         PT100120
     1        MQRTE,NKG,NHALV,NI                                        PT100130
      WRITE (6,2)                                                       PT100140
C     CHOOSE AND SET UP PARTICLE SIZE DISTRIBUTION                      PT100150
      IF (IDSTP.NE.0) GO TO (12,15,16,17,18,19,17,20,21,22,24,26),IDSTP PT100160
C**   TYPE 0: ARBITRARY USER-SUPPLIED DISTRIBUTION. THE NRADI VALUES    PT100170
C     OF FF(J) MUST BE GIVEN, ONE PER CARD, ON EQUAL INCREMENTS DELLR   PT100180
C     OF RADIUS AND READ IN ORDER, FROM SMALLEST RADIUS, RLO TO THE     PT100190
C     LARGEST:  NRADI MUST BE LESS THAN OR EQUAL TO  513.               PT100200
      WRITE (6,7)                                                       PT100210
      READ (5,1) RLO,DELLR                                              PT100220
      DO 9 J=1,NRADI                                                    PT100230
      R(J)=RLO+DELLR*FLOAT(J-1)                                         PT100240
    9 READ (5,1) FF(J)                                                  PT100250
      DO 10 J=1,NRADI,5                                                 PT100260
      JK=J+4                                                            PT100270
      IF(JK.GT.NRADI)JK=NRADI                                           PT100280
   10 WRITE (6,11)(R(K),FF(K),K=J,JK)                                   PT100290
      WRITE (6,11)                                                      PT100300
      FF(NRADI+1)=FF(NRADI)                                             PT100310
      RR(1)=RLO                                                         PT100320
      RR(2)=RLO+DELLR*FLOAT(NRADI-1)                                    PT100330
      MIN=0                                                             PT100340
      GO TO 28                                                          PT100350
C**   TYPE 1: LOG-NORMAL DISTRIBUTION                                   PT100360
   12 READ (5,1) RBAR,SIGMA,RLO,RHI                                     PT100370
C     SIGMA IS STANDARD DEVIATION, NOT LN(SIGMA)                        PT100380
      SIGIN=SIGMA                                                       PT100390
      SIGMA=ALOG(SIGMA)                                                 PT100400
      A=ABS(1.E0/(2.5066283E0*SIGMA))                                   PT100410
      IF ((RHI-RLO).LE.1.E-4) GO TO 13                                  PT100420
      RR(1)=RLO                                                         PT100430
      RR(3)=RHI                                                         PT100440
      GO TO 14                                                          PT100450
   13 RR(1)=RBAR*EXP(-4.E0*SIGMA)                                       PT100460
      RR(3)=RBAR*EXP(4.E0*SIGMA)                                        PT100470
   14 RR(2)=RBAR                                                        PT100480
      MIN=1                                                             PT100490
      WRITE (6,3) RBAR,SIGIN,RLO,RHI                                    PT100500
      AVOL=4.18879E0*(RBAR**3.E0)*EXP(4.5E0*SIGMA*SIGMA)                PT100510
C     HERE AND ELSEWHERE, AVOL IS THE VOLUME OBTAINED VIA               PT100520
C     ANALYTICAL INTEGRATION OVER THE LIMITS RLO =0 TO RHI =            PT100530
C     INFINITY: THAT CAN ONLY BE DONE FOR A FEW IDSTP CASES.            PT100540
      GO TO 28                                                          PT100550
C** TYPE 2: DOUBLE EXPONENTIAL F(R)=CUE*A*EXP(-A*R)+(1-CUE)*B*EXP(-B*R).PT100560
C      RESTRICTIONS: RHI.GT.RLO, B.GT.A.GE.0, 0.LE.CUE.LE.1.0.          PT100570
   15 READ (5,1) RLO,RHI,CUE,A,B                                        PT100580
      WRITE (6,4) RLO,RHI,CUE,A,B                                       PT100590
      RR(1)=RLO                                                         PT100600
      RR(3)=RHI                                                         PT100610
      RR(2)=0.5E0*(RLO+RHI)                                             PT100620
      MIN=1                                                             PT100630
      GO TO 28                                                          PT100640
C**   TYPE 3: DEIRMENDJIAN MODEL C. F(R) = 1.0, RLO.LE.R.LE.4*DELRD,   PT100650
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C       F(R)=(4*DELRD/R)**4, R.GE.(4*DELRD)                                    PT100660
C       NRADI IS READ IN EARLIER IN THE MAIN PROGRAM.                          PT100670
   16   DENS=1.378E+04                                                         PT100680
        DELRD=0.02E0                                                           PT100690
        RLO=0.02E0                                                             PT100700
        RHI=RLO+DELRD*FLOAT(NRADI-1)                                           PT100710
        RR(1)=RLO                                                              PT100720
        RR(3)=RHI                                                              PT100730
        MIN=1                                                                  PT100740
        RR(2)=RLO+4.E0*DELRD                                                   PT100750
        GO TO 28                                                               PT100760
C**     TYPE 4 AND TYPE 7: POWER LAW. F(R) = CUE*R**-A                         PT100770
C       RLO.LE.R.LE.RHI; VIS=VISIBILITY IN KILOMETERS.                         PT100780
   17   IF (IDSTP.EQ.4) GO TO 18                                               PT100790
C**     TYPE 7 PRESCRIBED PARAMETER.                                           PT100800
        READ (5,1) VIS                                                         PT100810
        RLO=0.1E0                                                              PT100820
        RHI=15.E0                                                              PT100830
        CUE=30.E0                                                              PT100840
        A=4.E0                                                                 PT100850
        DENS=11.E0**(5.E0-ALOG10(VIS))                                         PT100860
C**     TYPE 4 PRESCRIBED PARAMETERS.                                          PT100870
   18   IF (IDSTP.EQ.4) READ (5,1) RLO,RHI,CUE,A                               PT100880
        WRITE (6,5) RLO,RHI,CUE,A,VIS                                          PT100890
        RR(1)=RLO                                                              PT100900
        RR(3)=RHI                                                              PT100910
        RR(2)=(0.5E0*(RLO**(-A)+RHI**(-A)))**(-1.E0/A)                         PT100920
        MIN=1                                                                  PT100930
        GO TO 28                                                               PT100940
C**     TYPE 5: MODIFIED GAMMA/GENERALIZED KHIRGIAN-MAZIN                      PT100950
C       F(R) = (R**ALF)*EXP(-ALF*((R/RC)**GAM)/GAM)                            PT100960
C       RLO.LE.R.LE.RHI.                                                       PT100970
C**     TYPE 6: SPECIAL CASE FOR WATER FOGS OR CLOUDS,                         PT100980
C       IN WHICH CASE ELWC IS LIQUID WATER CONTENT                             PT100990
C       IN GRAMS PER CUBIC CENTIMETER:                                         PT101000
C       ELWC IS IGNORED IF IDSTP =/= 5.                                        PT101010
   19   READ (5,1) RLO,RHI,RC,ALF,GAM,ELWC                                     PT101020
        IF (IDSTP.EQ.6) DENS=ELWC                                              PT101030
        WRITE (6,6) RLO,RHI,RC,ALF,GAM                                         PT101040
        RR(1)=RLO                                                              PT101050
        RR(2)=RC                                                               PT101060
        RR(3)=RHI                                                              PT101070
        MIN=1                                                                  PT101080
        B=ALF/(GAM*RC**GAM)                                                    PT101090
        AVOL=4.1888*B**(-3./GAM)*GAMMA((ALF+4.)/GAM)/GAMMA((ALF+1.)/GAM)      PT101100
        GO TO 28                                                               PT101110
C**     TYPES 8,9,10: BIMODAL LOG-NORMAL DISTRIBUTIONS.                        PT101120
C       METHOD BELOW VALID FOR RBARC*EXP(-SGA).GT.RBARA*EXP(SGA)               PT101130
C**     TYPE 8: CONTINENTAL BIMODAL.                                           PT101140
   20   FOA=4.E03                                                              PT101150
        FOC=2.1E0                                                              PT101160
        SGA=0.74E0                                                             PT101170
        SGC=0.81E0                                                             PT101180
        RBARA=0.03E0                                                           PT101190
        RBARC=0.4E0                                                            PT101200
        GO TO 23                                                               PT101210
C**     TYPE 9: MARITIME BIMODAL.                                              PT101220
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   21 FOA=4.E02                                                          PT101230
      FOC=3.8E0                                                          PT101240
      SGA=0.68E0                                                         PT101250
      SGC=0.74E0                                                         PT101260
      RBARA=0.05E0                                                       PT101270
      RBARC=0.65E0                                                       PT101280
      GO TO 23                                                           PT101290
C**   TYPE 10: URBAN BIMODAL.                                            PT101300
   22 FOA=2.E04                                                          PT101310
      FOC=0.6E0                                                          PT101320
      SGA=0.63E0                                                         PT101330
      SGC=.77E0                                                          PT101340
      RBARA=0.04E0                                                       PT101350
      RBARC=0.63E0                                                       PT101360
C     CALCULATE RADII FOR TYPES 8,9,10.                                  PT101370
   23 RR(1)=RBARA*EXP(-4.E0*ABS(SGA))                                    PT101380
      RR(2)=RBARA                                                        PT101390
      RR(3)=RBARA*EXP(4.E0*ABS(SGA))                                     PT101400
      RR(4)=RBARC*EXP(-4.E0*ABS(SGC))                                    PT101410
      RR(5)=RBARC*EXP(4.E0*ABS(SGC))                                     PT101420
      MIN=2                                                              PT101430
       DO 60 J=1,4                                                       PT101440
      DO 60 I=1,4                                                        PT101450
      IF (RR(I+1).GT.RR(I)) GO TO 60                                     PT101460
      HH=RR(I)                                                           PT101470
      RR(I)=RR(I+1)                                                      PT101480
      RR(I+1)=HH                                                         PT101490
60    CONTINUE                                                           PT101500
      GO TO 28                                                           PT101510
C**   TYPE 11:                                                           PT101520
C     USER SUPPLIED BIMODAL CASE: FOA AND FOC ARE THE NUMBER DENSITIES   PT101530
C     FOR THE ACCUMULATION (SMALLER RBAR) AND COARSE MODES,              PT101540
C     RESPECTIVELY, IN PARTICLES PER CUBIC CENTIMETER.                   PT101550
C     SGA IS STD.DEVIATION FOR MODE A ** NOT LN(SIGMA) ***               PT101560
C     SGC IS STD.DEVIATION FOR MODE C ** NOT LN(SIGMA) ***               PT101570
C     *** NOTE, HOWEVER, THAT SGA AND SGC ARE THE LOGS OF THE            PT101580
C     STANDARD DEVIATIONS IN THE PRE-CODED CASES TYPE  8-10.             PT101590
   24 READ (5,1) FOA,FOC,RBARA,RBARC,SGA,SGC                             PT101600
      WRITE (6,25) FOA,RBARA,SGA,FOC,RBARC,SGC                           PT101610
      SGA=ABS(ALOG(SGA))                                                 PT101620
      SGC=ABS(ALOG(SGC))                                                 PT101630
      GO TO 23                                                           PT101640
C**   TYPE 12:  MARSHALL-PALMER RAIN MODEL.                              PT101650
C     C.F. MASON, PHYSICS OF CLOUDS, CH. ON RADAR METEOROLOGY.           PT101660
C     INPUT PARAMETER RAIN IS RAIN RATE IN MILLIMETERS/HOUR:             PT101670
C     ** EMA,CAYA, AND RHOA ARE REQUIRED FOR THIS DISTRIBUTION.          PT101680
   26 READ (5,1) RAIN                                                    PT101690
      ENZERO=0.08E0                                                      PT101700
      CAPL=41.E0*RAIN**(-0.21E0)                                         PT101710
      DENS=ENZERO/CAPL                                                   PT101720
      AVOL=PI*(CAPL**(-3.E0))*1.E12                                      PT101730
C     CONVERT UNITS FROM CM-4 TO (CM-3)*(MICROMETERS**(-1)):             PT101740
C     THE FACTOR OF 2 CONVERTS THE M-P FORMULA FROM DIAMETER-DATA TO     PT101750
C     RADIUS BASED FORM.                                                 PT101760
      ENZERO=2.E-4*ENZERO                                                PT101770
      CAPL=2.E-4*CAPL                                                    PT101780
      MIN=0                                                              PT101790
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      RR(1)=1.E-4                                                       PT101800
      RR(2)=2500.E0                                                     PT101810
      WRITE (6,27) RAIN,DENS                                            PT101820
C     THE NEXT BLOCK IS COMMON TO ALL DISTRIBUTIONS.                    PT101830
C     IT SETS THE NMAX VALUES OF RADIUS, R(KK).                         PT101840
   28 MAX=9                                                             PT101850
      NHALV=MAX-MIN                                                     PT101860
      NMAX=1+2**MAX                                                     PT101870
      NI=2**MIN                                                         PT101880
      NLAST=NI+1                                                        PT101890
      NKG=2**NHALV                                                      PT101900
      ENKG=FLOAT(NKG)                                                   PT101910
      DO 29 I=1,NI                                                      PT101920
      DR(I)=RR(I+1)-RR(I)                                               PT101930
      DO 29 K=1,NKG                                                     PT101940
      KK=(I-1)*NKG+K                                                    PT101950
   29 R(KK)=RR(I)+(FLOAT(K-1))*DR(I)/ENKG                               PT101960
      R(NMAX)=RR(NLAST)                                                 PT101970
C     BRANCH AGAIN CALCULATE THE DIFFERENT F(R) ON THE NMAX POINTS R(K) PT101980
      IF (IDSTP.NE.0) GO TO (31,33,35,38,41,41,39,43,43,43,43,46),IDSTR PT101990
C**   TYPE 0: ARBITRARY                                                 PT102000
      DELR=(RR(2)-RL0)/ENKG                                             PT102010
      DO 30 KK=1,NMAX                                                   PT102020
      JKK=1+(FLOAT(KK-1))*DELR/DELLR                                    PT102030
      RRJKK=RR(1)+DELLR*FLOAT(JKK-1)                                    PT102040
   30 F(KK)=FF(JKK)+(R(KK)-RRJKK)*(FF(JKK+1)-FF(JKK))/DELLR             PT102050
      GO TO 48                                                          PT102060
C**   TYPE 1: LOG NORMAL                                                PT102070
   31 DEN=2.E0*SIGMA*SIGMA                                              PT102080
      DO 32 KK=1,NMAX                                                   PT102090
      GNUM=ALOG(R(KK)/RBAR)                                             PT102100
   32 F(KK)=EXP(-GNUM*GNUM/DEN)*A/R(KK)                                 PT102110
      GO TO 48                                                          PT102120
C**   TYPE 2: DOUBLE EXPONENTIAL                                        PT102130
   33 DO 34 KK=1,NMAX                                                   PT102140
      FKK=(1.E0-CUE)*B*EXP(-B*R(KK))                                    PT102150
   34 F(KK)=FKK+CUE*A*EXP(-A*R(KK))                                     PT102160
      GO TO 48                                                          PT102170
C**   TYPE 3: DEIRMENDJIAN  MODEL C.                                    PT102180
   35 DO 36 KK=1,NMAX                                                   PT102190
   36 F(KK)=1.E0                                                        PT102200
      NKG1=NKG+1                                                        PT102210
      DO 37 KK=NKG1,NMAX                                                PT102220
   37 F(KK)=(RR(2)/R(KK))**4.E0                                         PT102230
      GO TO 48                                                          PT102240
C**   TYPES 4 AND 7: POWER LAW                                          PT102250
   38 GO TO 39                                                          PT102260
   39 DO 40 KK=1,NMAX                                                   PT102270
   40 F(KK)=CUE*R(KK)**(-A)                                             PT102280
      GO TO 48                                                          PT102290
C**   TYPE 5 AND TYPE 6:  MODIFIED GAMMA                                PT102300
   41 DO 42 KK=1,NMAX                                                   PT102310
   42 F(KK)=(EXP(-B*R(KK)**GAM))*R(KK)**ALF                             PT102320
      GO TO 48                                                          PT102330
C**   TYPES 8,9,10,11:   BIMODAL LOG-NORMAL DISTRIBUTIONS               PT102340
   43 DENA=2.E0*SGA*SGA                                                 PT102350
      DENC=2.E0*SGC*SGC                                                 PT102360
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      FAA=FOA/SGA                                                          PT102370
      FCC=FOC/SGC                                                          PT102380
      DO 44 KK=1,NMAX                                                      PT102390
      GNUMA=ALOG(R(KK)/RBARA)                                              PT102400
      GNUMC=ALOG(R(KK)/RBARC)                                              PT102410
      FA=FAA*EXP(-GNUMA*GNUMA/DENA)                                        PT102420
      FC=FCC*EXP(-GNUMC*GNUMC/DENC)                                        PT102430
   44 F(KK)=(FA+FC)/R(KK)                                                  PT102440
      DENS=FOA+FOC                                                         PT102450
      WRITE (6,45) DENS                                                    PT102460
      VOLA=4.18879E0*(RBARA**3.E0)*EXP(4.5E0*SGA*SGA)*FOA                  PT102470
      VOLC=4.18879E0*(RBARC**3.E0)*EXP(4.5E0*SGC*SGC)*FOC                  PT102480
      AVOL=(VOLA+VOLC)/DENS                                                PT102490
      GO TO 48                                                             PT102500
C**   TYPE 12: MARSHALL-PALMER RAIN MODEL                                  PT102510
   46 DO 47 KK=1,NMAX                                                      PT102520
   47 F(KK)=ENZERO*EXP(-CAPL*R(KK))                                        PT102530
C     CALCULATE NORMALIZED F(KK) AND SOME DRY VOLUMES USING ALL NMAX       PT102540
C     VALUES OF RADII.                                                     PT102550
C     (VOL=AVERAGE PARTICLE VOLUME IN A DISTRIBUTION). THE                 PT102560
C     NORMALIZATION AND FURTHER VOLUMES ARE RECALCULATED LATER             PT102570
C     BY THE HALVING INTEGRATION METHOD.                                   PT102580
   48 FSUM=0.E0                                                            PT102590
      IF(F(1).LT.0.E0)F(1)=0.0E0                                           PT102600
      DO 49 J=2,NMAX                                                       PT102610
      IF(F(J).LT.0.E0)F(J)=0.E0                                            PT102620
   49 FSUM=FSUM+0.5E0*(F(J)+F(J-1))*(R(J)-R(J-1))                          PT102630
      DO 50 J=1,NMAX                                                       PT102640
   50 F(J)=F(J)/FSUM                                                       PT102650
      WRITE (6,8) FSUM                                                     PT102660
      NRADI =NMAX                                                          PT102670
      IF (IDSTP.EQ.1.OR.IDSTP.EQ.5.OR.IDSTP.GE.8) WRITE (6,51) AVOL        PT102680
      VOL=0.E0                                                             PT102690
      DO 52 J=2,NMAX                                                       PT102700
   52 VOL=VOL+2.0944E0*(F(J)*R(J)**3.E0+F(J-1)*R(J-1)**3.E0)*(R(J)-R(J-    PT102710
     1       1))                                                           PT102720
      WRITE (6,53) VOL                                                     PT102730
C     THE VOLUME PER PARTICLE CALCULATED HERE IS OBTAINED USING            PT102740
C     ALL AVAILABLE (NMAX VALUES) VALUES FOR THE PARTICLE RADII.           PT102750
      WRITE (6,54)                                                         PT102760
      DO 56 INT=1,NI                                                       PT102770
      INF=INT+1                                                            PT102780
   56 WRITE (6,55) INT,RR(INT),RR(INF)                                     PT102790
      RETURN                                                               PT102800
    1 FORMAT (6E12.6,I3)                                                   PT102810
    2 FORMAT (1H ,//24H AEROSOL PARAMETERS ARE )                           PT102820
    3 FORMAT (1H+,24X,6HRBAR= ,E12.6,5X,7HSIGMA= ,E12.6,7H RLO = ,E12.6,   PT102830
     +         7H RHI = ,E12.6/)                                           PT102840
    4 FORMAT (1H+,24X,5HRLO= ,E10.4,1X,5HRHI= ,E10.4,1X,5HCVE= ,E10.4,     PT102850
     +         1X,3HA= ,E10.4,1X,3HB= ,E10.4/)                             PT102860
    5 FORMAT (1H+,24X,5HRLO= ,E10.4,1X,5HRHI= ,E10.4,1X,5HCVE= ,E10.4,     PT102870
     +         1X,3HA= ,E10.4,1X,4HVIS=,E10.4/)                            PT102880
    6 FORMAT (1H+,24X,5HRLO= ,E10.4,1X,5HRHI= ,E10.4,1X,4HRC= ,E10.4,1X,   PT102890
     +         5HALF= ,E10.4,1X,5HGAM= ,E10.4/)                            PT102900
    7 FORMAT (/1H ,5(26H   RADIUS    RELATIVE NO. )//)                     PT102910
    8 FORMAT (/46H NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = ,E14.7)    PT102920
   11 FORMAT (1X,10(1PE12.6,1X))                                           PT102930
```

```
25 FORMAT (/1X,7HN(A) = ,E12.6,2X,9H RBARA = ,E12.6,2X,12H SIGMA(A) =PT102940
  +        ,E12.6,/,1X,7HN(C) = ,E12.6,2X,9H RBARC = ,E12.6,2X,       PT102950
  +        12H SIGMA(C) = ,F12.6/)                                    PT102960
27 FORMAT (/1X,42H MARSHALL-PALMER RAIN MODEL : RAIN RATE = ,1PE10.3,PT102970
  +        21H MM PER HOUR, DENS = ,1PE12.6,8H PART/CC)               PT102980
45 FORMAT (/,1H ,50H*** BIMODAL DISTRIBUTION...EQUIVALENT  DENSITY ISPT102990
  +        ,1PE13.6,18H  PARTICLES PER CC,/)                          PT103000
51 FORMAT(/45H AVERAGE ANALYTIC DRY VOLUME PER PARTICLE IS ,3X,       PT103010
  +        1PE12.6,18H CUBIC MICROMETERS)                             PT103020
53 FORMAT (1X,47HAVERAGE NUMERICAL DRY VOLUME IS                      PT103030
  +        1PE12.6,18H CUBIC MICROMETERS/)                            PT103040
54 FORMAT (1X,10X,35H SIZE-INTERVALS USED ARE AS FOLLOWS/)            PT103050
55 FORMAT (1H ,14H INTERVAL NO. ,I3,5X,7HRMIN = ,F11.5,5X,8H RMAX =   PT103060
  +        ,F11.5)                                                    PT103070
   END                                                               PT103080
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      SUBROUTINE AGXPT2(RELHUM,CTSUM,CSSUM,CRSUM,TVOL,TMASS,DENS,CATTN,  PT2X0100
     1           TEMP,DELTA,NINDX,IAPX,IW)                               PT2X0110
      DOUBLE PRECISION EMD,CAYD,ALPHAD,QTD,QSD,QRD,O1STRD,O2STRD,DBLE    PT2X0120
      REAL KEXT,KEXTT,KEXOLD                                             PT2X0130
      DIMENSION F(513),R(513),DR(8),RR(9),C(100),P(100),PSUM(100)        PT2X0140
      DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100),PSUMT(100)   PT2X0150
      DIMENSION PHH(100),PGG(100),PHHT(100),SCAT(100)                    PT2X0160
      EQUIVALENCE (PHHT(1),PC(1)),(PGG(1),RMS(1)),(PHHT(1),OL(1))        PT2X0170
      COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,IT,ITT,NRADI         PT2X0180
      COMMON /BK3/F,R,PSUM,SCAT,RR,DR,WAVE,EM,CAY,EMM,PI,IDSTP,          PT2X0190
     1       MQRTE,NKG,NHALV,NI                                          PT2X0200
C     IN THIS SUBROUTINE THE FOLLOWING CONVENTIONS ARE USED IN           PT2X0210
C     PREFIXING VARIABLE NAMES:                                          PT2X0220
C     THE LETTER  C  IS USED FOR CROSS-SECTIONS                          PT2X0230
C     THE LETTER  Q  IS USED FOR EFFICIENCY FACTORS                      PT2X0240
C     THE LETTER  K  IS USED FOR EXTINCTION COEF. PER UNIT PATH (KM)     PT2X0250
C     THE LETTER  T  IS A SUFFIX FOR TOTAL VALUES                        PT2X0260
C     THE LETTER  O  IS A PREFIX FOR OMEGA SUB 1 AND 2 CALCULATIONS      PT2X0270
C     FOR THE IDSTP=6 AND 12 CASES, DENS IS USED TO TRANSFER THE         PT2X0280
C     LIQUID WATER CONTENT FROM THE MAIN PROGRAM TO THIS SUBROUTINE:     PT2X0290
C     ELWC IS USED AS THE AEROSOL CONCENTRATION FOR THOSE CASES.         PT2X0300
      IF (IDSTP.EQ.6.OR.IDSTP.EQ.12) ELWC=DENS                           PT2X0310
      OLSTAR=0.0E0                                                       PT2X0320
      OM2=0.E0                                                           PT2X0330
      CTSUMT=0.0E+00                                                     PT2X0340
      CSSUMT=0.0E+00                                                     PT2X0350
      DENST=0.E0                                                         PT2X0360
      CRSUMT=0.0E+00                                                     PT2X0370
      EMM=1.E0                                                           PT2X0380
      NLINES=0                                                           PT2X0390
      BH=1.056E-3                                                        PT2X0400
C     FACTORS BH AND CH ARE USED IN SIZE ADJUSTMENTS                     PT2X0410
C     FH IS THE SATURATION RATIO                                         PT2X0420
      FH=RELHUM/100.E0                                                   PT2X0430
      CH=FH/(1.E0-FH)                                                    PT2X0440
      CONCT=0.0E0                                                        PT2X0450
      KEXTT=0.E0                                                         PT2X0460
C     CONVERT VOL PER PARTICLE RECEIVED FROM MAIN PROGRAM VIA VARIABLE   PT2X0470
C     TVOL TO DRY VOLUME PER PARTICLE IN CUBIC CENTIMETERS               PT2X0480
      DRYVOL=TVOL*1.0E-12                                                PT2X0490
      TVOL=0.E0                                                          PT2X0500
      TMASS=0.E0                                                         PT2X0510
      DO 6 J=1,IT                                                        PT2X0520
      PSUMT(J)=0.0E0                                                     PT2X0530
      PHH(J)=0.0E0                                                       PT2X0540
      PGG(J)=0.E0                                                        PT2X0550
    6 PSUM(J)=0.0E+00                                                    PT2X0560
C     CONVERT TEMP. TO KELVIN FOR SUBROUTINE WATER USAGE                 PT2X0570
      TEMK=TEMP+273.16E0                                                 PT2X0580
C     SKIP SUBROUTINE WATER FOR THE IDSTP = 12 CASE, AND READ THE        PT2X0590
C     OPTICAL DATA FOR RAIN AS EMUA,CAYA,ETC...NEEDED BECAUSE CASE       PT2X0600
C     IDSTP=12 MAY BE AT WAVELENGTHS LONGER THAN FOUND IN ROUTINE        PT2X0610
C     WATER.                                                             PT2X0620
      IF (IDSTP.EQ.12) GO TO 8                                           PT2X0630
      CALL WATER(WAVE,EMW,CAYW,TEMK,RHOW)                                PT2X0640
C     SUBROUTINE WATER RETURNS INTERPOLATED VALUES FOR EMW, CAYW AND     PT2X0650
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C     RHOW AT WAVELENGTH = WAVE AND AT TEMPERATURE = TEMK (DEG K).       PT2X0660
C     EMW IS REAL PART OF INDEX OF REFR FOR PURE WATER AT TEMP(DEG C).   PT2X0670
C     CAYW IS IMAG. PART OF INDEX OF REFR. FOR PURE WATER:               PT2X0680
C     CAYW, HERE IS POSITIVE, BUT TREATED AS NEGATIVE IN MIE-ROUTINE.    PT2X0690
C     RHOW IS MASS DENSITY(GM/CC) AT TEMPERATURE = TEMP (DEG C).         PT2X0700
      WRITE (6,9) EMW,CAYW,TEMP,RHOW                                     PT2X0710
C     BEGIN LOOP OVER AEROSOL COMPONENTS INDEXED BY NK                   PT2X0720
    8 DO 32 NK=1,NINDX                                                   PT2X0730
C     BYPASS READ OF EMA,CAYA,EIC. FOR IDSTP=6 CASE..USE WATER DATA      PT2X0740
      IF (IDSTP.NE.6) GO TO 10                                           PT2X0750
      EMA=EMW                                                            PT2X0760
      CAYA=CAYW                                                          PT2X0770
      RHOA=RHOW                                                          PT2X0780
      CONC=ELWC                                                          PT2X0790
      EMUA=0.0E0                                                         PT2X0800
      GO TO 11                                                           PT2X0810
C     ***  READ OPTICAL AND PHYSICAL DATA    ***                       PT2X0820
   10 READ (5,2) EMA,CAYA,EMUA,RHOA,CONC                                 PT2X0830
      IF (IW.EQ.0) EMA=EMW                                               PT2X0840
      IF (IW.EQ.0) CAYA=CAYW                                             PT2X0850
      IF(IDSTP.NE.12) GO TO 11                                           PT2X0860
      EMUA=0.0E0                                                         PT2X0870
      RHOW=RHOA                                                          PT2X0880
      EMW=EMA                                                            PT2X0890
      CAYW=CAYA                                                          PT2X0900
   11 IF (RHOA.LE.0.0E0) RHOA=1.E0                                       PT2X0910
      IF (EMA.LT.1.E-30) GO TO 44                                        PT2X0920
      WRITE (6,3) NK,EMA,CAYA,RHOA,EMUA,CONC                             PT2X0930
      BHT=BH*(298.E0/TEMK)                                               PT2X0940
      IF (EMUA.LE.0.01) CH=0.0                                           PT2X0950
      BC=BHT*CH                                                          PT2X0960
      A=1.E0+((RHOA/RHOW)*EMUA*CH)                                       PT2X0970
      AC=A**(1.E0/3.E0)                                                  PT2X0980
C     ADJUST EM,RHO AND CAY PER G. HANEL/ADVANCES IN GEOPHYS/1976        PT2X0990
      RHO=RHOW+((RHOA-RHOW)/A)                                           PT2X1000
      EM=EMW+((EMA-EMW)/A)                                               PT2X1010
      CAY=CAYW+((CAYA-CAYW)/A)                                           PT2X1020
      CAY=CAY/EM                                                         PT2X1030
C     INITIALIZE QUANTITIES USED TO HOLD RUNNING SUMMATIONS OVER         PT2X1040
C     RADII FOR THE CURRENT COMPONENT                                    PT2X1050
      FSUMG=0.E0                                                         PT2X1060
      CTSUM=0.E0                                                         PT2X1070
      CSSUM=0.E0                                                         PT2X1080
      CRSUM=0.0E0                                                        PT2X1090
      VOL=0.0E0                                                          PT2X1100
      OL1SUM=0.0E0                                                       PT2X1110
      OL2SUM=0.E0                                                        PT2X1120
      DO 13 J=1,IT                                                       PT2X1130
   13 PSUM(J)=0.0E0                                                      PT2X1140
C     PRINT HEADER IF DETAILED MIE RESULTS ARE TO BE PRINTED             PT2X1150
      IF (MQRTE.EQ.12345) WRITE (6,5)                                    PT2X1160
C     BEGIN ACTUAL LOOP OVER RADIUS INTERVALS FOR THE CURRENT NK VALUE   PT2X1170
C     THIS LOOP IS THE ONE IN WHICH THE MIE CALCULATIONS ARE CALLED      PT2X1180
C     INTERVALS ARE INDEXED BY I.  THERE ARE NI SUCH INTERVALS.          PT2X1190
      DO 26 I=1,NI                                                       PT2X1200
      NRADI=2                                                            PT2X1210
      MERROR=0                                                           PT2X1220
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      D=RR(I+1)-RR(I)                                                    PT2X1230
C     RIT IS THE ADJUSTED RADIUS FOR THE RELATIVE HUMIDITY TO BE USED    PT2X1240
C     IN THIS PARTICULAR RUN OR PASS                                     PT2X1250
      RIT=RR(I)*AC -(BC/AC)                                              PT2X1260
      IF (RIT.LT.RR(I).OR.RR(I).LT.0.04E0) RIT=RR(I)                     PT2X1270
      ALPHA=2.E0*PI*RIT/WAVE                                             PT2X1280
C     ROUTINE MIEGX DOES THE ACTUAL MIE CALCULATIONS.                    PT2X1290
C     NOTE THAT THE IMAG. PART OF THE REFRACTIVE INDEX (CAY) HAS BEEN    PT2X1300
C     NORMALIZED THROUGH DIVISION BY THE REAL PART (EM) BEFORE ITS       PT2X1310
C     VALUE IS PASSED TO THE MIE-ROUTINE.                                PT2X1320
C     MIEGX RETURNS THE EXTINCTION EFFICIENCY FACTOR AS QT               PT2X1330
C     MIEGX RETURNS THE SCATTERING EFFICIENCY FACTOR AS QS               PT2X1340
C     MIEGX RETURNS THE BACK-SCATTERING (RADAR) EFFIC. FACTOR AS QR      PT2X1350
C     MIEGX RETURNS THE AVERAGE INTENSITY (I1+I2)/2 IN THE ARRAY P()     PT2X1360
C     AT ANGLES = ARCCOS(  C( )  ),WHERE C( ) IS SET-UP BY               PT2X1370
C     SUBROUTINE ANGLE OR SUBROUTINE GUSET                               PT2X1380
C     MIEGX ALSO RETURNS THE 2-ND AND 3-RD LEGENDRE EXPANSION COEF.      PT2X1390
C     (OMEGA SUB 1 AND OMEGA SUB 2) AS O1STAR AND O2STAR.                PT2X1400
C     IERROR IS RETURNED AS UNITY IF MIE-SERIES DID NOT CONVERGE         PT2X1410
C     AFTER 999 TERMS WERE COMPUTED.                                     PT2X1420
      EMD=DBLE (EM)                                                      PT2X1430
      CAYD=DBLE (CAY)                                                    PT2X1440
      ALPHAD=DBLE (ALPHA)                                                PT2X1450
      CALL MIEGX(EMD,CAYD,ALPHAD,QTD,QSD,QRD,P,O1STRD,O2STRD,IERROR,     PT2X1460
     +           IAPX)                                                   PT2X1470
      EM=SNGL(EMD)                                                       PT2X1480
      CAY=SNGL(CAYD)                                                     PT2X1490
      ALPHA=SNGL(ALPHAD)                                                 PT2X1500
      QT=SNGL(QTD)                                                       PT2X1510
      QS=SNGL(QSD)                                                       PT2X1520
      QR=SNGL(QRD)                                                       PT2X1530
      O1STAR=SNGL(O1STRD)                                                PT2X1540
      O2STAR=SNGL(O2STRD)                                                PT2X1550
      IF (IERROR.EQ.1) MERROR=MERROR+1                                   PT2X1560
C     MERROR IS USED TO COUNT THE NUMBER OF TIMES IERROR HAS             PT2X1570
C     BEEN RETURNED WITH THE VALUE OF 1. EXECUTION WILL BE               PT2X1580
C     TERMINATED WHEN MERROR REACHES A VALUE OF TEN.                     PT2X1590
      IF (MQRTE.EQ.12345) WRITE (6,4) RIT,RR(I),F(I),ALPHA,QT,QS,QR      PT2X1600
      KK=1+(I-1)*NKG                                                     PT2X1610
      FKK=F(KK)                                                          PT2X1620
      FKKA=FKK*PI*RIT**2.E0                                              PT2X1630
      VOLHH=4.1888*FKK*RIT**3.E0                                         PT2X1640
      OL1HH=O1STAR*FKKA*QT                                               PT2X1650
      OL2HH=O2STAR*FKKA*QT                                               PT2X1660
      CTHH=QT*FKKA                                                       PT2X1670
      CSHH=QS*FKKA                                                       PT2X1680
      CRHH=QR*FKKA                                                       PT2X1690
      DO 14 J=1,IT                                                       PT2X1700
      PHH(J)=SNGL(P(J))*FKK                                              PT2X1710
14    CONTINUE                                                           PT2X1720
      RIT=RR(I+1)*AC-(BC/AC)                                             PT2X1730
      IF (RIT.LT.RR(I+1).OR.RR(I+1).LT.0.04E0) RIT=RR(I+1)               PT2X1740
      ALPHA=2.E0*PI*RIT/WAVE                                             PT2X1750
      EMD=DBLE (EM)                                                      PT2X1760
      CAYD=DBLE (CAY)                                                    PT2X1770
      ALPHAD=DBLE (ALPHA)                                                PT2X1780
      CALL MIEGX(EMD,CAYD,ALPHAD,QTD,QSD,QRD,P,O1STRD,O2STRD,IERROR,     PT2X1790
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     +           IAPX)                                                    PT2X1800
      EM=SNGL(EMD)                                                       PT2X1810
      CAY=SNGL(CAYD)                                                     PT2X1820
      ALPHA=SNGL(ALPHAD)                                                 PT2X1830
      QT=SNGL(QTD)                                                       PT2X1840
      QS=SNGL(QSD)                                                       PT2X1850
      QR=SNGL(QRD)                                                       PT2X1860
      O1STAR=SNGL(O1STRD)                                                PT2X1870
      O2STAR=SNGL(O2STRD)                                                PT2X1880
      IF (IERROR.EQ.1) MERROR=MERROR+1                                   PT2X1890
      KK1=1+NKG*I                                                        PT2X1900
      FKK1=F(KK1)                                                        PT2X1910
      IF (MQRTE.EQ.12345) WRITE (6,4) RIT,RR(I+1),FKK1,ALPHA,QT,QS,QR    PT2X1920
      FKK1A=FKK1*PI*RIT**2.E0                                            PT2X1930
      VOLHH=(VOLHH+4.188E0*FKK1*RIT**3.E0)*D*0.5E0                       PT2X1940
      OL1HH=(OL1HH+FKK1A*QT*O1STAR)*D*0.5E0                              PT2X1950
      OL2HH=(OL2HH+FKK1A*QT*O2STAR)*D*0.5E0                              PT2X1960
      CTHH=(CTHH+QT*FKK1A)*D*.5E0                                        PT2X1970
      CSHH=(CSHH+QS*FKK1A)*D*.5E0                                        PT2X1980
      CRHH=(CRHH+QR*FKK1A)*D*.5E0                                        PT2X1990
      DO 15 J=1,IT                                                       PT2X2000
      PHH(J)=(PHH(J)+SNGL(P(J)))*FKK1)*D*0.5E0                           PT2X2010
15    CONTINUE                                                           PT2X2020
      FF=0.5E0*D*(FKK+FKK1)                                              PT2X2030
      NT=1                                                               PT2X2040
C**   DEL1=0.E0                                                          PT2X2050
      N=1                                                                PT2X2060
   16 NJ=NT                                                              PT2X2070
      NT=2*NT                                                            PT2X2080
      D=0.5E0*D                                                          PT2X2090
      VOLGG=0.0E0                                                        PT2X2100
      OL1GG=0.0E0                                                        PT2X2110
      OL2GG=0.E0                                                         PT2X2120
      CTGG=0.E0                                                          PT2X2130
      CSGG=0.E0                                                          PT2X2140
      CRGG=0.E0                                                          PT2X2150
      FT=0.E0                                                            PT2X2160
      DO 17 J=1,IT                                                       PT2X2170
   17 PGG(J)=0.E0                                                        PT2X2180
C     NEXT LOOP HANDLES INTERMEDIATE PARTICLE SIZES..THOSE LYING BETWEEN PT2X2190
C     RMIN AND RMAX FOR THE CURRENT INTERVAL WHOSE INDEX IS I.           PT2X2200
      DO 19 JG=1,NJ                                                      PT2X2210
      KK=1+(I-1)*NKG+(2*JG-1)*(NKG/NT)                                   PT2X2220
      RIT=R(KK)*AC -(BC/AC)                                              PT2X2230
      IF (RIT.LT.R(KK).OR.R(KK).LT.0.04E0) RIT=R(KK)                     PT2X2240
      ALPHA=2.E0*PI*RIT/WAVE                                             PT2X2250
      EMD=DBLE (EM)                                                      PT2X2260
      CAYD=DBLE (CAY)                                                    PT2X2270
      ALPHAD=DBLE (ALPHA)                                                PT2X2280
      CALL MIEGX(EMD,CAYD,ALPHAD,QTD,QSD,QRD,P,O1STRD,O2STRD,IERROR,     PT2X2290
     +           IAPX)                                                   PT2X2300
      EM=SNGL(EMD)                                                       PT2X2310
      CAY=SNGL(CAYD)                                                     PT2X2320
      ALPHA=SNGL(ALPHAD)                                                 PT2X2330
      QT=SNGL(QTD)                                                       PT2X2340
      QS=SNGL(QSD)                                                       PT2X2350
      QR=SNGL(QRD)                                                       PT2X2360
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      O1STAR=SNGL(O1STRD)                                                PT2X2370
      O2STAR=SNGL(O2STRD)                                                PT2X2380
      IF (IERROR.EQ.1) MERROR=MERROR+1                                   PT2X2390
      IF (MERROR.GT.10) GO TO 39                                         PT2X2400
      IF (MQRTE.EQ.12345) WRITE (6,4) RIT,R(KK),F(KK),ALPHA,QT,QS,QR     PT2X2410
      NRADI=NRADI+1                                                      PT2X2420
      FKK=F(KK)                                                          PT2X2430
      FKKA=FKK*PI*RIT**2.E0                                              PT2X2440
      VOLGG=4.1888E0*FKK*RIT**3.0E0+VOLGG                                PT2X2450
      OL1GG=OL1GG+O1STAR*FKKA*QT                                         PT2X2460
      OL2GG=OL2GG+O2STAR*FKKA*QT                                         PT2X2470
      CTGG=CTGG+QT*FKKA                                                  PT2X2480
      CSGG=CSGG+QS*FKKA                                                  PT2X2490
      CRGG=CRGG+QR*FKKA                                                  PT2X2500
      DO 18 J=1,IT                                                       PT2X2510
      PGG(J)=PGG(J)+SNGL(P(J))*FKK                                       PT2X2520
18    CONTINUE                                                           PT2X2530
   19 FT=FT+FKK                                                          PT2X2540
C     ADD RESULTS ACCUMULATED DURING PREVIOUS HALVINGS TO THOSE FOUND    PT2X2550
C     FOR THE NEW RADII TREATED WITHIN THE LOOP OVER INDEX JG            PT2X2560
      VOLHHT=0.5E0*VOLHH+D*VOLGG                                         PT2X2570
      OL1HHT=0.5E0*OL1HH+D*OL1GG                                         PT2X2580
      OL2HHT=0.5E0*OL2HH+D*OL2GG                                         PT2X2590
      CTHHT=0.5E0*CTHH+D*CTGG                                            PT2X2600
      CSHHT=0.5E0*CSHH+D*CSGG                                            PT2X2610
      CRHHT=0.5E0*CRHH+D*CRGG                                            PT2X2620
      DO 20 J=1,IT                                                       PT2X2630
   20 PHHT(J)=.5E0*PHH(J)+D*PGG(J)                                       PT2X2640
      FFT=0.5E0*FF+D*FT                                                  PT2X2650
      IF (CTHHT.LT.1.E-35) GO TO 22                                      PT2X2660
      DEL=ABS(VOLHHT-VOLHH)/ABS(VOLHHT)                                  PT2X2670
C     DELETE THE C** FROM COLS 1-3 BELOW AND ABOVE, AND DELETE THE       PT2X2680
C     FOLLOWING -IF- STATEMENT TO IMPLEMENT A DOUBLE CHECK FOR           PT2X2690
C     CONVERGENCE.                                                       PT2X2700
C**   IF(DEL.GT.DELTA)GO TO 22                                           PT2X2710
C**   IF(DEL.LE.DEL1)GO TO 24                                            PT2X2720
C**   DEL1=DEL                                                           PT2X2730
      IF (DEL.LE.DELTA) GO TO 21                                         PT2X2740
      GO TO 22                                                           PT2X2750
   21 IF (N.GT.2) GO TO 24                                               PT2X2760
C     DO NOT ALLOW DEL LESS THAN DELTA EXIT UNLESS AT LEAST TWO          PT2X2770
C     HAVINGS HAVE BEEN DONE                                             PT2X2780
   22 IF (N.EQ.NHALV) GO TO 24                                           PT2X2790
C     MUST EXIT WHEN NHALV HALVINGS HAVE BEEN DONE EVEN IF THE DELTA     PT2X2800
C     CRITERION HAS NOT BEEN SATISFIED..SINCE NO MORE VALUES OF RADII    PT2X2810
C     ARE AVAILABLE.                                                     PT2X2820
      FF=FFT                                                             PT2X2830
      CRHH=CRHHT                                                         PT2X2840
      OL1HH=OL1HHT                                                       PT2X2850
      OL2HH=OL2HHT                                                       PT2X2860
      CSHH=CSHHT                                                         PT2X2870
      CTHH=CTHHT                                                         PT2X2880
      VOLHH=VOLHHT                                                       PT2X2890
      DO 23 J=1,IT                                                       PT2X2900
   23 PHH(J)=PHHT(J)                                                     PT2X2910
      N=N+1                                                              PT2X2920
      GO TO 16                                                           PT2X2930
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   24 FSUMG=FSUMG+FFT                                                    PT2X2940
      IF(N.EQ.NHALV) WRITE(6,124) I                                      PT2X2950
C     SUM QUANTITIES OVER ALL INTERVALS TREATED UP UNTIL NOW             PT2X2960
      CTSUM=CTSUM+CTHHT                                                  PT2X2970
      CSSUM=CSSUM+CSHHT                                                  PT2X2980
      CRSUM=CRSUM+CRHHT                                                  PT2X2990
      VOL=VOL+VOLHHT                                                     PT2X3000
      OL1SUM=OL1SUM+OL1HHT                                               PT2X3010
      OL2SUM=OL2SUM+OL2HHT                                               PT2X3020
C     AT THIS POINT, PSUM() IS THE RUNNING SUM OF THE AVG. INTENSITY     PT2X3030
C     AS SUMMED OVER SIZES                                               PT2X3040
      DO 25 J=1,IT                                                       PT2X3050
   25 PSUM(J)=PSUM(J)+PHHT(J)                                            PT2X3060
      WRITE (6,27) NK,I,NRADI,CTHHT                                      PT2X3070
      NLINES=NLINES+NRADI                                                PT2X3080
C      END LOOP OVER HALVING INTERVALS INDEXED BY I                      PT2X3090
   26 CONTINUE                                                           PT2X3100
C     RENORMALIZE VALUES OF CTSUM, ETC.                                  PT2X3110
      CTSUM=CTSUM/FSUMG                                                  PT2X3120
      CSSUM=CSSUM/FSUMG                                                  PT2X3130
      CRSUM=CRSUM/FSUMG                                                  PT2X3140
      VOL=VOL/FSUMG                                                      PT2X3150
      OL1SUM=OL1SUM/FSUMG                                                PT2X3160
      OL2SUM=OL2SUM/FSUMG                                                PT2X3170
      DO 28 J=1,IT                                                       PT2X3180
   28 PSUM(J)=PSUM(J)/FSUMG                                              PT2X3190
C     CALCULATE PARTICLE NUMBER DENSITY(NO. PER CC) AS DENSC             PT2X3200
      DENSC=CONC/(RHOA*DRYVOL)                                           PT2X3210
C     OVERRIDE CALCULATED VALUE OF DENSC WITH DENS IF LLLL =1            PT2X3220
      IF (LLLL.EQ.1) DENSC=DENS                                          PT2X3230
C     RECALCULATE CONC FROM OTHER INPUT DATA IF LLLL=1                   PT2X3240
      IF (LLLL.EQ.1) CONC=DENS*RHOA*DRYVOL                               PT2X3250
C     REPLACE DENS BY DENSC FOR LATER USE BY AGXPT3                      PT2X3260
      DENS=DENSC                                                         PT2X3270
C     WEIGHT CTSUM,ETC. BY NUMBER DENSITIES (DENSC) FOR THIS COMPONENT   PT2X3280
      CTSUM=CTSUM*DENSC                                                  PT2X3290
      CSSUM=CSSUM*DENSC                                                  PT2X3300
      CRSUM=CRSUM*DENSC                                                  PT2X3310
      VOL=VOL*DENSC                                                      PT2X3320
      OL1SUM=OL1SUM*DENSC                                                PT2X3330
      OL2SUM=OL2SUM*DENSC                                                PT2X3340
      DO 29 J=1,IT                                                       PT2X3350
   29 PSUM(J)=PSUM(J)*DENSC                                              PT2X3360
C     NOW, SUM OVER COMPONENTS INDEXED BY NK                             PT2X3370
C     CONCT IS THE TOTAL DRY-AEROSOL CONCENTRATION IN MG PER CC          PT2X3380
      CONCT=CONCT+1.E3*CONC                                              PT2X3390
      DENST=DENST+DENSC                                                  PT2X3400
      OLSTAR=OL1SUM+OLSTAR                                               PT2X3410
      OM2=OL2SUM+OM2                                                     PT2X3420
      CTSUMT=CTSUMT+CTSUM                                                PT2X3430
C     AT THIS POINT, CTSUMT IS THE TOTAL EXTINCTION CROSS SECTION        PT2X3440
C     (IN SQ. MICRONS) AS SUMMED OVER ALL COMPONENTS WHICH               PT2X3450
C     HAVE BEEN DEALT WITH THUS FAR                                      PT2X3460
      CSSUMT=CSSUMT+CSSUM                                                PT2X3470
      CRSUMT=CRSUMT+CRSUM                                                PT2X3480
      DO 30 J=1,IT                                                       PT2X3490
   30 PSUMT(J)=PSUM(J)+PSUMT(J)                                          PT2X3500
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      VOL=VOL*1.E-12                                                    PT2X3510
C     TVOL IS THE TOTAL VOLUME (IN CM**3) OCCUPIED BY THE AEROSOL       PT2X3520
C     PARTICLES.  TVOL IS NOT ACTUALLY USED IN THIS VERSION OF          PT2X3530
C     PROGRAM AGAUS.                                                    PT2X3540
      TVOL=VOL+TVOL                                                     PT2X3550
      EMASS=VOL*RHO                                                     PT2X3560
      TMASS=TMASS+EMASS                                                 PT2X3570
      KEXOLD=KEXTT                                                      PT2X3580
      KEXTT=CTSUMT*1.E-3                                                PT2X3590
      KEXT=KEXTT-KEXOLD                                                 PT2X3600
      WRITE (6,31) NK,VOL,EMASS,KEXT                                    PT2X3610
C     VPF(VOL) IS THE VOLUME PACKING FRACTION: THAT IS, THE FRACTION    PT2X3620
C     OF EACH CC OF SPACE WHICH IS FILLED BY AEROSOL MATERIAL BELONGING PT2X3630
C     TO THE CURRENT COMPONENT NK.                                      PT2X3640
C     TMASS IS THE TOTAL MASS OF AEROSOL FOUND IN 1 CC OF SPACE.        PT2X3650
C     EMASS IS THE MASS OF AEROSOL MATERIAL PER CC ASSOCIATED WITH      PT2X3660
C     THE CURRENT COMPONENT NK.                                         PT2X3670
C     KEXT IS THE EXTINCTION COEF.(PER KM) WHICH IS ASSOCIATED WITH     PT2X3680
C     THE CURRENT COMPONENT--AS IF IT ALONE WERE PRESENT.               PT2X3690
C     KEXTT IS THE SUM OF THE KEXT'S OVER ALL COMPONENTS.               PT2X3700
C     END LOOP OVER AEROSOL COMPONENTS INDEXED BY NK.                   PT2X3710
      IF (NINDX.GT.1) WRITE (6,42) NK                                   PT2X3720
      IF (MQRTE.EQ.12345) WRITE (6,43)                                  PT2X3730
   32 CONTINUE                                                          PT2X3740
      IF(NINDX.GT.1)WRITE (6,33) TMASS,KEXTT                            PT2X3750
      WRITE (6,34) NLINES                                               PT2X3760
      DENS=DENST                                                        PT2X3770
      NRADI=NLINES                                                      PT2X3780
C     NOW, PERFORM THE FINAL RENORMALIZATIONS TO OBTAIN CTSUM, ETC.     PT2X3790
C     VALUES REPRESENTATIVE OF A SINGLE AVERAGE PARTICLE.               PT2X3800
C     CTSUM BECOMES THE EXTINCTION CROSSECTION IN SQ. MICROMETERS PER   PT2X3810
C     AVERAGE PARTICLE. THE OTHER QUANTITIES CARRY SIMILAR MEANINGS.    PT2X3820
      DO 35 J=1,IT                                                      PT2X3830
   35 PSUM(J)=PSUMT(J)/DENST                                            PT2X3840
      OLSTAR=OLSTAR/CTSUMT                                              PT2X3850
      OM2=OM2/CTSUMT                                                    PT2X3860
      IF (IAPX.GT.0) WRITE (6,36) OLSTAR,OM2                            PT2X3870
C     THE FOLLOWING 2 STMTS ARE FOR THE GHG ANALYTIC PHASE FUNCTION.    PT2X3880
      IF (IAPX.GT.0) OL(2)=OLSTAR                                       PT2X3890
      IF (IAPX.GT.0) OL(3)=OM2                                          PT2X3900
      CTSUM=CTSUMT/DENST                                                PT2X3910
      CSSUM=CSSUMT/DENST                                                PT2X3920
      CRSUM=CRSUMT/DENST                                                PT2X3930
C     THE FOLLOWING STMT IS FOR THE GHG ANALYTIC PHASE FUNCTION.        PT2X3940
      IF (IAPX.GT.0) OL(1)=CSSUM/CTSUM                                  PT2X3950
C     CALCULATE ATTENUATION COEFS. IN SQ.METERS PER MILLIGRAM           PT2X3960
      CATTN=CTSUMT*1.E-12/CONCT                                         PT2X3970
      CATTNW=1.E-12*KEXTT/TMASS                                         PT2X3980
      WRITE (6,37) CATTN                                                PT2X3990
      IF(RELHUM.GT.1.0)WRITE (6,38) CATTNW                              PT2X4000
      GO TO 41                                                          PT2X4010
   39 WRITE (6,40)                                                      PT2X4020
      STOP                                                              PT2X4030
   44 WRITE (6,45) EMA                                                  PT2X4040
      STOP                                                              PT2X4050
   41 RETURN                                                            PT2X4060
    2 FORMAT (4F10.6,E15.7)                                             PT2X4070
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 3 FORMAT (1HO,6H INDX=,I3,4H M= ,F10.6,6H K = -,F10.6,9H1.  MASS ,  PT2X4080
  +        10HDENSITY = ,F8.6,                                        PT2X4090
  +        17H GROWTH FACTOR = ,F8.4,9H. CONC = ,1PE12.5,7H  GM/CC/) PT2X4100
 4 FORMAT (1X,F10.5,6(2X,1PE11.5))                                    PT2X4110
 5 FORMAT (//54H R(MICRONS)  DRY  RADIUS     N(R)       MIE  SIZE    PT2X4120
  +        ,36HQ (EXT)      Q(SCA)          Q(RADAR)/)                PT2X4130
 9 FORMAT (1HO,39HINDEX OF REFRACTION FOR PURE WATER IS: ,F8.6,       PT2X4140
  +        3H - ,F8.6,1HI//,1X,25HMASS DENSITY OF WATER AT ,F6.2,     PT2X4150
  +          11H DEG C IS: ,F8.2,6H GM/CC)                            PT2X4160
24 FORMAT(/52H *** CONVERGENCE LEVEL NOT REACHED FOR INTERVAL NO. ,   PT2X4170
  +         I3,4H ***/)                                               PT2X4180
27 FORMAT(1H ,19H FOR COMPONENT NO. ,I3,15H  INTERVAL NO. ,I3,1H ,14,PT2X4190
  +        43H RADII WERE USED.  CONTRIBUTION TO CTSUM = ,1PE12.6)    PT2X4200
31 FORMAT (1HO,19H FOR COMPONENT NO. ,I2,12H :    VPF = ,1PE12.5,     PT2X4210
  +          24H   MASS CONCENTRATION = ,E12.5,21H  GM/CC.  KEXT =    PT2X4220
  +        E12.5,7H PER KM)                                           PT2X4230
33 FORMAT (1HO,28H TOTAL MASS CONCENTRATION = ,1PE12.5,7H GM/CC;,     PT2X4240
  +       15H TOTAL KEXT =  ,E12.5,7H PER KM)                         PT2X4250
34 FORMAT (/1X,32H TOTAL NUMBER OF RADII USED WAS ,I5)                PT2X4260
36 FORMAT (/16H  OMEGA SUB-1 = ,1PE20.13/,16H  OMEGA SUB-2 = ,       PT2X4270
  +        1PE20.13/)                                                 PT2X4280
37 FORMAT (1HO,21H ATTENUATION COEF. = ,1PE12.5,12H  SQ-METERS/,     PT2X4290
  +        33HMILLIGRAM OF DRY AEROSOL MATERIAL)                      PT2X4300
38 FORMAT (1HO,21H ATTENUATION COEF. = ,1PE12.5,12H  SQ-METERS/,     PT2X4310
  +        33HMILLIGRAM OF WET AEROSOL MATERIAL)                      PT2X4320
40 FORMAT (///47H *** EXECUTION TERMINATING DUE TO MORE THAN TEN,    PT2X4330
  +        30H ERRORS IN MIE-SUBROUTINE  ***//)                       PT2X4340
42 FORMAT (1HO/,1X,10X,30(1H*),33H  END OF AEROSOL COMPONENT CYCLE , PT2X4350
  +        7HNUMBER ,I3,2X,30(1H*)//)                                 PT2X4360
43 FORMAT (1HO)                                                      PT2X4370
45 FORMAT (///,1X,11H***** EMA (,F10.6,20H) IS EITHER ZERO OR ,      PT2X4380
  +35HNEGATIVE - PROGRAM TERMINATED *****)                           PT2X4390
   END                                                               PT2X4400
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      SUBROUTINE AGXPT3(CTSUM,CSSUM,CRSUM,GNU,DENS,NINDX,NUNIT,IANG,     PT3X0100
     +                  ITOT,IAPX)                                       PT3X0110
      DIMENSION F(513),R(513),C(100),PSUM(100),RR(9),DR(8)               PT3X0120
      DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100),SCAT(100)    PT3X0130
      COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,IT,ITT,NRADI         PT3X0140
      COMMON /BK3/F,R,PSUM,SCAT,RR,DR,WAVE,EM,CAY,EMM,PI,IDSTP,          PT3X0150
     1       MQRTE,NKG,NHALV,NI                                          PT3X0160
      ALBDO=CSSUM/CTSUM                                                  PT3X0170
      CAYNG=-CAY                                                         PT3X0180
C     PFACT IS USED TO CONVERT AVG. INTENSITY PSUM() INTO PHASE-         PT3X0190
C     FUNCTIONS. SFACT IS USED TO CONVERT PSUM INTO SCATTERING           PT3X0200
C     FRACTIONS,NORMALIZED PER THE SMOKE OBSCURATION MODEL (ACT).        PT3X0210
C     THE INTEGRAL OF SCAT() OVER SOLID ANGLE SHOULD YIELD THE           PT3X0220
C     TOTAL SCATTERING CROSS-SECTION IN SQ. METERS.                      PT3X0230
      PFACT=WAVE*WAVE/(PI*CTSUM*EMM*EMM)                                 PT3X0240
      SFACT=WAVE*WAVE*DENS*1.E-6/(4.EQ*PI*PI)                            PT3X0250
      DO 15 J=1,IT                                                       PT3X0260
      SCAT(J)=SFACT*PSUM(J)                                              PT3X0270
      PSUM(J)=PSUM(J)*PFACT                                              PT3X0280
      IF (((NCRDS.EQ.2).OR.(NCRDS.EQ.3)).AND.((ITOT.EQ.1).OR.(ITOT.EQ.3)PT3X0290
     + ).AND.(IAPX.EQ.0))  WRITE (NUNIT,3)  SCAT(J),PSUM(J),C(J),J      PT3X0300
   15 CONTINUE                                                           PT3X0310
      IF (NINDX.GE.2) WRITE (6,12)                                       PT3X0320
      IF (IAPX.EQ.0) WRITE (6,10)                                        PT3X0330
      WRITE (6,4) IDSTP,WAVE,EM,CAYNG,CTSUM,CSSUM,ALBDO                  PT3X0340
C     CONVERT AVG. CROSS-SECTIONS TO COEFFICIENTS (PER KM)               PT3X0350
      CTSUM=CTSUM*1.0E-3*DENS                                            PT3X0360
      CSSUM=CSSUM*1.0E-3*DENS                                            PT3X0370
      CRSUM=CRSUM*1.0E-3*DENS                                            PT3X0380
      WRITE (6,13) CTSUM,CSSUM,CRSUM                                     PT3X0390
      WRITE (6,14) GNU,DENS                                              PT3X0400
      IF (IT.LT.2) GO TO 21                                              PT3X0410
      IF (IANG.EQ.0) GO TO 18                                            PT3X0420
C     WRITE PHASE FUNCTION AT EQUAL ANGULAR INCREMENTS                   PT3X0430
      WRITE (6,1)                                                        PT3X0440
      WRITE (6,6)                                                        PT3X0450
      DO 16 J=1,IT,4                                                     PT3X0460
      K=J+3                                                              PT3X0470
      IF (K.GT.IT) K=IT                                                  PT3X0480
   16 WRITE (6,9) (H(I),PSUM(I),I=J,K)                                   PT3X0490
C     WRITE SCATTERING FRACTIONS AT EQUAL ANGULAR INCREMENTS             PT3X0500
      WRITE (6,2)                                                        PT3X0510
      WRITE (6,7)                                                        PT3X0520
      DO 17 J=1,IT,4                                                     PT3X0530
      K=J+3                                                              PT3X0540
      IF (K.GT.IT) K=IT                                                  PT3X0550
   17 WRITE (6,9) (H(I),SCAT(I),I=J,K)                                   PT3X0560
      GO TO 21                                                           PT3X0570
   18 WRITE (6,1)                                                        PT3X0580
      WRITE (6,5)                                                        PT3X0590
C     WRITE PHASE FUNCTION AT GAUSS-LEGENDRE QUADRATURE ANGLES           PT3X0600
      DO 19 J=1,IT,4                                                     PT3X0610
      K=J+3                                                              PT3X0620
      IF (K.GT.IT) K=IT                                                  PT3X0630
   19 WRITE (6,8) (C(I),PSUM(I),I=J,K)                                   PT3X0640
      WRITE (6,11)                                                       PT3X0650
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      CALL GAUS(PSUM,NUNIT,ITOT)                                        PT3X0660
C     ROUTINE GAUS GENERATES AND PRINTS/PUNCHES THE LEGENDRE            PT3X0670
C     EXPANSION COEFS (OMEGAS) FOR THE PHASE FUNCTION.                  PT3X0680
C     CHECK TO SEE IF SNG. SCAT. ALBEDO (ALBDO) COMPUTED DIRECTLY       PT3X0690
C     FROM CROSS-SECTIONS AGREES WITH THAT FOUND FROM THE LEGENDRE      PT3X0700
C     EXPANSION OF PHASE-FUNCTION.                                      PT3X0710
      IF ((ABS(OL(1)-ALBDO)/ALBDO).GT.1.E-4) WRITE (6,20)               PT3X0720
   21 RETURN                                                            PT3X0730
    1 FORMAT (//1H ,50X,14HPHASE FUNCTION/,1X,38X,40H(INTEGRAL NORMALIZEPT3X0740
     +D TO 4 PI OMEGA ZERO)//)                                          PT3X0750
    2 FORMAT (1H //,37X,43HSCATTERING FRACTIONS ( ACT   NORMALIZATION)/)PT3X0760
    3 FORMAT (3(E12.6,1X),I5)                                           PT3X0770
    4 FORMAT(1H0,41H  DISTRIBUTION  WAVELENGTH     REFRACTIVE,9X,       PT3X0780
     + 20HEXTINCTION X SECTION,8X,20HSCATTERING X SECTION,12X,5HALBDO/1HPT3X0790
     + ,6X,4HTYPE,6X,9H(MICRONS),8X,5HINDEX,16X,12H(SQ MICRONS),13X,    PT3X0800
     +        12H(SQ MICRONS)/1H ,I9,4X,F11.4,F10.4,2H(1,F7.4,2HI),     PT3X0810
     +        1P3E25.14)                                                PT3X0820
    5 FORMAT (1H0,3X,4(5H   MU,8X,17HPHASE FUNCTION   )/)               PT3X0830
    6 FORMAT (1H0,18X,4(20H  ANGLE   PF-VALUE  )/)                      PT3X0840
    7 FORMAT (1H0,18X,4(20H  ANGLE     SCAT    )/)                      PT3X0850
    8 FORMAT (1H ,4(F13.9,E17.10))                                      PT3X0860
    9 FORMAT (1H ,18X,4(1X,F6.2,1X,E12.7))                              PT3X0870
   10 FORMAT (1H1)                                                      PT3X0880
   11 FORMAT (1H0/,1X,25X,1HL,20X,16HL-TH COEFFICIENT,23X,5HRMS  ,      PT3X0890
     +        9HDEVIATION/)                                            PT3X0900
   12 FORMAT (52H THIS IS A MIXED CASE * SUBSEQUENT REFRACTIVE INDEX ,  PT3X0910
     +        34HPRINT-OUTS ARE NOT GENERALLY VALID/)                  PT3X0920
   13 FORMAT (1H0,10H K(EXT) = ,1PE13.7,11H; K(SCA) = ,E13.7,           PT3X0930
     +        11H; K(RAD) = ,E13.7,11H ALL PER KM/)                    PT3X0940
   14 FORMAT (/14H WAVENUMBER = ,1PE12.6,5H CM-1,5X,10HDENSITY = ,E12.6,PT3X0950
     +        17H PARTICLES PER CC/)                                   PT3X0960
   20 FORMAT (//51H *** WARNING *** ORDER OF QUADRATURE  IS TOO SMALL , PT3X0970
     +        38HFOR GOOD PHASE FUNCTION REPRESENTATION//12H *** VALUES PT3X0980
     +       ,55HOF ALBDO AND OL(1) DISAGREE BY MORE THAN .01 PERCENT **PT3X0990
     +        ,34HLARGER VALUE OF 'IT' IS NEEDED ***/)                 PT3X1000
      END                                                               PT3X1010
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      SUBROUTINE MIEGX(EM,CAY,ALPHA,SGT,SGS,SGR,P,O1STAR,O2STAR,IERROR,  MEGX0100
     1           IAPX)                                                   MEGX0110
C     TO CALCULATE BESSEL FUNCTIONS OF THE SECOND KIND ALSO             MEGX0120
C       REMOVE THE C*.S FROM STATEMENTS CIRCA 124, 179 AND              MEGX0130
C       CHANGE THE 'DO' PARAMETERS FOR STMT. TO: DO 190 K=1,2.          MEGX0140
      IMPLICIT DOUBLEPRECISION(A-H,O-Z)                                 MEGX0150
      REAL PL,OL,RMS,PC,C,H,ALBDO,P,SNGL                                MEGX0160
      DIMENSION C(100),EYE1(100),EYE2(100),EYE3(100),EYE4(100),P(100)   MEGX0170
      DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100)             MEGX0180
      COMPLEX*16 A(1000),ACAPN,ANUM,ZDEN,ZPDT,ZRPDT,ZAN,ZANP,Y,RF,RRF,  MEGX0190
     1         RRFX,WM1,FNA,FNB,TC1,FNAP,FNBP,FNAPP,FNBPP,TC2,WFN(2)     MEGX0200
      DIMENSION T(5),TA(4),TB(2),TC(2),TD(2),TE(2),TF(2),TG(2)          MEGX0210
      DIMENSION ELTRMX(4,100,2),PI(4,100),TAU(4,100)                    MEGX0220
      COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,IT,ITT,NRADI        MEGX0230
      EQUIVALENCE (WFN(1),TA(1)),(FNA,TB(1)),(FNB,TC(1)),(FNAP,TD(1))   MEGX0240
      EQUIVALENCE (FNBP,TE(1)),(FNAPP,TF(1)),(FNBPP,TG(1))              MEGX0250
      EQUIVALENCE (ELTRMX(1),PL(1)),(PI(1),PL(1601)),(TAU(1),PL(2401))  MEGX0260
      EQUIVALENCE (A(1),PL(3201))                                       MEGX0270
      X=ALPHA                                                           MEGX0280
      IERROR=0                                                          MEGX0290
      PII=3.141592653589D+00                                            MEGX0300
      CAYE=CAY*EM                                                       MEGX0310
      NMX=0                                                             MEGX0320
      S=1.DO                                                            MEGX0330
      RF=DCMPLX(EM,-CAYE)                                               MEGX0340
      NMX=IFIX(X*(EM+CAYE))+9                                           MEGX0350
      RRF=1.DO/RF                                                       MEGX0360
      RX=1.DO/X                                                         MEGX0370
      RRFX=RRF*RX                                                       MEGX0380
      DO 1 J=1,IT                                                       MEGX0390
      PI(1,J)=0.DO                                                      MEGX0400
      PI(2,J)=1.DO                                                      MEGX0410
      TAU(1,J)=0.DO                                                     MEGX0420
      TAU(2,J)=C(J)                                                     MEGX0430
    1 CONTINUE                                                          MEGX0440
      T(1)=DCOS(X)                                                      MEGX0450
      T(2)=DSIN(X)                                                      MEGX0460
      WM1=DCMPLX(T(1),-T(2))                                            MEGX0470
      WFN(1)=DCMPLX(T(2),T(1))                                          MEGX0480
      WFN(2)=RX*WFN(1)-WM1                                              MEGX0490
      T(1)=CAYE*X                                                       MEGX0500
      N=1                                                               MEGX0510
      NDIM=1000                                                         MEGX0520
      IF (NMX.LT.NDIM) NDELTA=NMX                                       MEGX0530
      IF (NMX.GT.NDIM) NDELTA=NDIM                                      MEGX0540
      NMX=0                                                             MEGX0550
      IF (N.EQ.1) GO TO 4                                               MEGX0560
    2 EN=DFLOAT(N)                                                      MEGX0570
      T(1)=2.DO*EN-1.DO                                                 MEGX0580
      T(2)=EN-1.DO                                                      MEGX0590
      T(3)=2.DO*EN+1.DO                                                 MEGX0600
      DO 3 J=1,IT                                                       MEGX0610
      PI1J=PI(1,J)                                                      MEGX0620
      PI2J=PI(2,J)                                                      MEGX0630
      CJ=C(J)                                                           MEGX0640
C     THE FOLLOWING STMT IS FOR THE GHG ANALYTIC PHASE FUNCTION.        MEGX0650
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      IF (IAPX.GT.0) CJ=1.D0                                              MEGX0660
      S2T=(1.0D+00-CJ*CJ)                                                 MEGX0670
      PI(3,J)=(T(1)*PI2J*CJ-EN*PI1J)/T(2)                                 MEGX0680
      TAU(3,J)=CJ*(PI(3,J)-PI1J)-T(1)*S2T*PI2J+TAU(1,J)                   MEGX0690
    3 CONTINUE                                                            MEGX0700
      WM1=WFN(1)                                                          MEGX0710
      WFN(1)=WFN(2)                                                       MEGX0720
      WFN(2)=T(1)*RX*WFN(1)-WM1                                           MEGX0730
    4 CONTINUE                                                            MEGX0740
C     CALCULATE RATIO OF BESSEL FNS OF CONSECUTIVE ORDER                  MEGX0750
      IF (N.LT.(NMX+1)) GO TO 9                                           MEGX0760
      NMX=NMX+NDELTA                                                      MEGX0770
      NMIN=NMX+1-NDELTA                                                   MEGX0780
      V=DFLOAT(NMX)+0.5D0                                                 MEGX0790
      Y=RF*X                                                              MEGX0800
      ZANP=2.D0/Y                                                         MEGX0810
      ZNUM=ZANP*V                                                         MEGX0820
      ZPDT=ZNUM                                                           MEGX0830
      V=V+1.D0                                                            MEGX0840
      ZDEN=ZANP*V                                                         MEGX0850
      ZNUM=ZDEN-1.D0/ZNUM                                                 MEGX0860
    5 ZRPDT=ZNUM/ZDEN                                                     MEGX0870
      ZPDT=ZRPDT*ZPDT                                                     MEGX0880
      IF (DABS(DREAL(ZRPDT)-1.D0).LT.1.D-10) GO TO 7                      MEGX0890
      IF (V.LT.20000.D0) GO TO 6                                          MEGX0900
      WRITE (6,1000) ALPHA,EM,CAY                                         MEGX0910
      IERROR=1                                                            MEGX0920
      GO TO 20                                                            MEGX0930
    6 V=V+1.D0                                                            MEGX0940
      ZAN=ZANP*V                                                          MEGX0950
      ZNUM=ZAN-1.D0/ZNUM                                                  MEGX0960
      ZDEN=ZAN-1.D0/ZDEN                                                  MEGX0970
      GO TO 5                                                             MEGX0980
    7 CONTINUE                                                            MEGX0990
      J=NMX                                                               MEGX1000
    8 JJ=J-NMX+NDELTA                                                     MEGX1010
      A(JJ)=-(DFLOAT(J))/Y+ZPDT                                           MEGX1020
      J=J-1                                                               MEGX1030
      IF (J.LT.NMIN) GO TO 9                                              MEGX1040
      ZPDT=(2.D0*DFLOAT(J)+1.D0)/Y-1.D0/ZPDT                              MEGX1050
      GO TO 8                                                             MEGX1060
    9 CONTINUE                                                            MEGX1070
      J=N-NMX+NDELTA                                                      MEGX1080
      ACAPN=A(J)                                                          MEGX1090
      IF (N.GT.1) GO TO 11                                                MEGX1100
C     THIS PART FOR N EQUAL 1 ONLY                                        MEGX1110
      TC1=ACAPN*RRF+RX                                                    MEGX1120
      TC2=ACAPN*RF+RX                                                     MEGX1130
      FNA=(TC1*TA(3)-TA(1))/(TC1*WFN(2)-WFN(1))                           MEGX1140
      FNB=(TC2*TA(3)-TA(1))/(TC2*WFN(2)-WFN(1))                           MEGX1150
      FNAP=FNA                                                            MEGX1160
      FNBP=FNB                                                            MEGX1170
      T(1)=1.5D0                                                          MEGX1180
      TB(1)=T(1)*TB(1)                                                    MEGX1190
      TB(2)=T(1)*TB(2)                                                    MEGX1200
      TC(1)=T(1)*TC(1)                                                    MEGX1210
      TC(2)=T(1)*TC(2)                                                    MEGX1220
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```
      DO 10 J=1,IT                                                          MEGX1230
      TAU2J=TAU(2,J)                                                        MEGX1240
      ELTRMX(1,J,1)=TB(1)+TC(1)*TAU2J                                       MEGX1250
      ELTRMX(2,J,1)=TB(2)+TC(2)*TAU2J                                       MEGX1260
      ELTRMX(3,J,1)=TC(1)+TB(1)*TAU2J                                       MEGX1270
      ELTRMX(4,J,1)=TC(2)+TB(2)*TAU2J                                       MEGX1280
C*    ELTRMX(1,J,2)=TB(1)-TC(1)*TAU2J                                       MEGX1290
C*    ELTRMX(2,J,2)=TB(2)-TC(2)*TAU2J                                       MEGX1300
C*    ELTRMX(3,J,2)=TC(1)-TB(1)*TAU2J                                       MEGX1310
C*    ELTRMX(4,J,2)=TC(2)-TB(2)*TAU2J                                       MEGX1320
   10 CONTINUE                                                              MEGX1330
      QEXT=2.D0*(TB(1)+TC(1))                                               MEGX1340
      QSCAT=(TB(1)*TB(1)+TB(2)*TB(2)+TC(1)*TC(1)+TC(2)*TC(2))/0.75D0        MEGX1350
      CTBROS=0.D0                                                           MEGX1360
      SUMW=0.D0                                                             MEGX1370
      O2STAR=0.D0                                                           MEGX1380
      SUMRR=2.D0*(TB(1)-TC(1))                                              MEGX1390
      SUMRI=2.D0*(TB(2)-TC(2))                                              MEGX1400
      N=2                                                                   MEGX1410
      GO TO 2                                                               MEGX1420
   11 CONTINUE                                                              MEGX1430
      TC1=ACAPN*RRF+EN*RX                                                   MEGX1440
      TC2=ACAPN*RF+EN*RX                                                    MEGX1450
      FNA=(TC1*TA(3)-TA(1))/(TC1*WFN(2)-WFN(1))                             MEGX1460
      FNB=(TC2*TA(3)-TA(1))/(TC2*WFN(2)-WFN(1))                             MEGX1470
      T(5)=EN                                                               MEGX1480
      T(4)=T(1)/(T(5)*T(2))                                                 MEGX1490
      T(2)=(T(2)*(T(5)+1.D0))/T(5)                                          MEGX1500
      CTBROS=CTBROS+T(2)*(TD(1)*TB(1)+TD(2)*TB(2)+TE(1)*TC(1)+TE(2)*        MEGX1510
     1       TC(2))+T(4)*(TD(1)*TE(1)+TD(2)*TE(2))                          MEGX1520
      S=-S                                                                  MEGX1530
      SUMRR=SUMRR+S*T(3)*(TB(1)-TC(1))                                      MEGX1540
      SUMRI=SUMRI+S*T(3)*(TB(2)-TC(2))                                      MEGX1550
C     O1STAR CALCULATION                                                    MEGX1560
      SUMW=SUMW+(TB(1)*TD(1)+TB(2)*TD(2)+TC(1)*TE(1)+TC(2)*TE(2))*T(2)*     MEGX1570
     1       4.D0+4.D0*T(4)*(TD(1)*TE(1)+TD(2)*TE(2))                       MEGX1580
      IF (N.LT.3) GO TO 12                                                  MEGX1590
C     O2STAR CALCULATION                                                    MEGX1600
      F1=TF(1)*TF(1)+TF(2)*TF(2)+TG(1)*TG(1)+TG(2)*TG(2)                    MEGX1610
      F2=TB(1)*TF(1)+TB(2)*TF(2)+TC(1)*TG(1)+TC(2)*TG(2)                    MEGX1620
      F3=TD(1)*TG(1)+TD(2)*TG(2)+TE(1)*TF(1)+TE(2)*TF(2)                    MEGX1630
      ENL1=EN-1.D0                                                          MEGX1640
      COF1=2.5D0*((EN-2.D0)*ENL1-3.D0)**2.D0*(2.D0*EN-3.D0)/((EN-2.D0)*     MEGX1650
     1       ENL1*(2.D0*EN-1.D0)*(2.D0*EN-5.D0))                            MEGX1660
      COF2=7.5D0*(EN-2.D0)*(EN+1.D0)/(2.D0*EN-1.D0)                         MEGX1670
      COF3=15.D0/ENL1                                                       MEGX1680
      O2STAR=O2STAR+COF1*F1+COF2*F2+COF3*F3                                 MEGX1690
   12 CONTINUE                                                              MEGX1700
      QEXT=QEXT+T(3)*(TB(1)+TC(1))                                          MEGX1710
      T(4)=TB(1)*TB(1)+TB(2)*TB(2)+TC(1)*TC(1)+TC(2)*TC(2)                  MEGX1720
      QSCAT=QSCAT+T(3)*T(4)                                                 MEGX1730
      T(2)=EN*(EN+1.D0)                                                     MEGX1740
      T(1)=T(3)/T(2)                                                        MEGX1750
      K=(N/2)*2                                                             MEGX1760
      DO 13 J=1,IT                                                          MEGX1770
      PI3J=PI(3,J)                                                          MEGX1780
      TAU3J=TAU(3,J)                                                        MEGX1790
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```
      ELTRMX(1,J,1)=ELTRMX(1,J,1)+T(1)*(TB(1)*PI3J+TC(1)*TAU3J)          MEGX1800
      ELTRMX(2,J,1)=ELTRMX(2,J,1)+T(1)*(TB(2)*PI3J+TC(2)*TAU3J)          MEGX1810
      ELTRMX(3,J,1)=ELTRMX(3,J,1)+T(1)*(TC(1)*PI3J+TB(1)*TAU3J)          MEGX1820
      ELTRMX(4,J,1)=ELTRMX(4,J,1)+T(1)*(TC(2)*PI3J+TB(2)*TAU3J)          MEGX1830
C*    IF (K.EQ.N) GO TO 130                                              MEGX1840
C*    ELTRMX(1,J,2)=ELTRMX(1,J,2)+T(1)*(TB(1)*PI3J-TC(1)*TAU3J)          MEGX1850
C*    ELTRMX(2,J,2)=ELTRMX(2,J,2)+T(1)*(TB(2)*PI3J-TC(2)*TAU3J)          MEGX1860
C*    ELTRMX(3,J,2)=ELTRMX(3,J,2)+T(1)*(TC(1)*PI3J-TB(1)*TAU3J)          MEGX1870
C*    ELTRMX(4,J,2)=ELTRMX(4,J,2)+T(1)*(TC(2)*PI3J-TB(2)*TAU3J)          MEGX1880
C*    GO TO 140                                                          MEGX1890
C* 3  ELTRMX(1,J,2)=ELTRMX(1,J,2)+T(1)*(-TB(1)*PI3J+TC(1)*TAU3J)         MEGX1900
C*    ELTRMX(2,J,2)=ELTRMX(2,J,2)+T(1)*(-TB(2)*PI3J+TC(2)*TAU3J)         MEGX1910
C*    ELTRMX(3,J,2)=ELTRMX(3,J,2)+T(1)*(-TC(1)*PI3J+TB(1)*TAU3J)         MEGX1920
C*    ELTRMX(4,J,2)=ELTRMX(4,J,2)+T(1)*(-TC(2)*PI3J+TB(2)*TAU3J)         MEGX1930
   13 CONTINUE                                                           MEGX1940
      IF (N.LT.5) GO TO 14                                               MEGX1950
      IF (T(4).LT.1.0D-10) GO TO 16                                      MEGX1960
   14 N=N+1                                                              MEGX1970
      DO 15 J=1,IT                                                       MEGX1980
      PI(1,J)=PI(2,J)                                                    MEGX1990
      PI(2,J)=PI(3,J)                                                    MEGX2000
      TAU(1,J)=TAU(2,J)                                                  MEGX2010
      TAU(2,J)=TAU(3,J)                                                  MEGX2020
   15 CONTINUE                                                           MEGX2030
      FNAPP=FNAP                                                         MEGX2040
      FNBPP=FNBP                                                         MEGX2050
      FNAP=FNA                                                           MEGX2060
      FNBP=FNB                                                           MEGX2070
      GO TO 2                                                            MEGX2080
   16 CONTINUE                                                           MEGX2090
C     WRITE (6,800) N                                                    MEGX2100
      DO 18 J=1,IT                                                       MEGX2110
      DO 18 K=1,1                                                        MEGX2120
      DO 17 I=1,4                                                        MEGX2130
      T(I)=ELTRMX(I,J,K)                                                 MEGX2140
   17 CONTINUE                                                           MEGX2150
      ELTRMX(1,J,K)=T(3)*T(3)+T(4)*T(4)                                  MEGX2160
      ELTRMX(2,J,K)=T(1)*T(1)+T(2)*T(2)                                  MEGX2170
      ELTRMX(3,J,K)=T(1)*T(3)+T(2)*T(4)                                  MEGX2180
   18 ELTRMX(4,J,K)=(T(2)*T(3)-T(4)*T(1))                                MEGX2190
C     ELTRMX(2,I,J) IS THE VERTICAL COMPONENT SCATTERING I1 (EYE1)       MEGX2200
C     ELTRMX(1,I,J) IS THE HORIZONTAL COMPONENT SCATTERING I2            MEGX2210
      DO 19 J=1,IT                                                       MEGX2220
      EYE1(J)=ELTRMX(2,J,1)                                              MEGX2230
      EYE2(J)=ELTRMX(1,J,1)                                              MEGX2240
      EYE3(J)=ELTRMX(3,J,1)                                              MEGX2250
      EYE4(J)=-1.D0*ELTRMX(4,J,1)                                        MEGX2260
      P(J)=SNGL((EYE1(J)+EYE2(J))/2.D0)                                  MEGX2270
   19 CONTINUE                                                           MEGX2280
      T(1)=2.D0*RX**2.D0                                                 MEGX2290
      SGT=QEXT*T(1)                                                      MEGX2300
      SGS=QSCAT*T(1)                                                     MEGX2310
      CTBROS=2.D0*CTBROS*T(1)                                            MEGX2320
      O1STAR=3.D0*SUMW/(X*X*SGT)                                         MEGX2330
      O2STAR=4.D0*O2STAR/(X*X*SGT)                                       MEGX2340
      SGR=(SUMRR*SUMRR+SUMRI*SUMRI)*RX*RX                                MEGX2350
   20 RETURN                                                             MEGX2360
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C                                                                       MEGX2370
 1000 FORMAT (52H V GT 20000 ERROR IN CONTINUED FRACTIONS MIE ROUTINE,  MEGX2380
     1        11H*** ALPHA =,D12.6,6H EM = ,D12.6,7H CAY = ,D12.6/)     MEGX2390
      END                                                               MEGX2400
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```
      SUBROUTINE GAUS(F,NUNIT,ITOT)                                     GAUS0100
      DIMENSION C(100),F(100)                                           GAUS0110
      DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100)             GAUS0120
      COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,IT,ITT,NRADI        GAUS0130
C     THE FOLLOWING STEPS CALCULATE THE LEGENDRE POLYNOMIALS PL(,)      GAUS0140
C     WHICH WILL BE USED BY SUBROUTINE GAUS IN FINDING THE GAUSS-       GAUS0150
C     LEGENDRE EXPANSION COEFFICIENTS FOR THE PHASE FUNCTION.           GAUS0160
      DO 9 I=1,IT                                                       GAUS0170
      PL(1,I)=1.0E+00                                                   GAUS0180
    9 PL(2,I)=C(I)                                                      GAUS0190
      DO 10 LL=2,ITT                                                    GAUS0200
      EL=LL                                                             GAUS0210
      LN=LL+1                                                           GAUS0220
      DO 11 I=1,IT                                                      GAUS0230
   11 PL(LN,I)=((2.E+00*EL-1.E+00)*C(I)*PL(LN-1,I)-(EL-1.0E+00)*PL(LN-  GAUS0240
     1       2,I))/EL                                                   GAUS0250
   10 CONTINUE                                                          GAUS0260
C      INITIALIZE ARRAY PC() USED FOR RUNNING SUMMATION                 GAUS0270
      DO 1 I=1,IT                                                       GAUS0280
    1 PC(I)=0.E+00                                                      GAUS0290
C      LOOPS 2 AND 3 CALCULATE EXPANSION COEFS. FOR FUNCTION F( )       GAUS0300
C      VIA GAUSS-LEGENDRE QUADRATURE. THE COEFS. GO INTO ARRAY OL()     GAUS0310
      DO 3 LL=1,IT                                                      GAUS0320
      L=LL-1                                                            GAUS0330
      EL=FLOAT(L)                                                       GAUS0340
      SUM=0.E+00                                                        GAUS0350
      DO 2 I=1,IT                                                       GAUS0360
    2 SUM=SUM+H(I)*F(I)*PL(LL,I)                                        GAUS0370
    3 OL(LL)=SUM*(EL+0.5E+00)                                           GAUS0380
C      LOOPS 4 AND 5 RECONSTRUCT THE FUNCTION F() AS PC() USING THE     GAUS0390
C      COEFS. OL() FOUND ABOVE,AND THE RMS-DEVIATION BETWEEN F() AND    GAUS0400
C      PC() AS EACH ADDITIONAL TERM IN THE LEGENDRE SERIES IS ADDED.    GAUS0410
      DO 5 J=1,IT                                                       GAUS0420
      RMS(J)=0.E+00                                                     GAUS0430
      DO 4 I=1,IT                                                       GAUS0440
      PC(I)=PC(I)+OL(J)*PL(J,I)                                         GAUS0450
    4 RMS(J)=RMS(J)+(F(I)-PC(I))*(F(I)-PC(I))                           GAUS0460
    5 RMS(J)=SQRT(RMS(J)/FLOAT(IT))                                     GAUS0470
      DO 7 I=1,IT                                                       GAUS0480
      II=I-1                                                            GAUS0490
C     WRITE/PUNCH THE VALUES OF THE EXP. COEFS. OL() ON NUNIT.          GAUS0500
      IF (((NCRDS.EQ.1).OR.(NCRDS.EQ.3)).AND.((ITOT.EQ.1).OR.(ITOT.EQ.3)GAUS0510
     + )) WRITE (NUNIT,6) OL(I),II                                      GAUS0520
    7 WRITE (6,8) II,OL(I),RMS(I)                                       GAUS0530
      RETURN                                                            GAUS0540
    6 FORMAT (E25.14,1X,I5)                                             GAUS0550
    8 FORMAT (1H ,20X,I6,1PE38.15,E35.15)                               GAUS0560
      END                                                               GAUS0570
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```
      SUBROUTINE GUSET(Z,P,PI)                                          GUST0100
C      THIS ROUTINE CALCULATES THE ABSCISSAE XKN()                      GUST0110
C      AND GAUSS-LEGENDRE WEIGHTS AKN() FOR NUMERICAL INTEGRATION       GUST0120
C      VIA GAUSS-LEGENDRE QUADRATURE OF ORDER N                         GUST0130
      DIMENSION Z(100),P(513),XKN(100),AKN(100)                         GUST0140
      DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100),C(100)      GUST0150
      EQUIVALENCE (C(1),XKN(1)),(H(1),AKN(1))                           GUST0160
      COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,IT,ITT,NRADI        GUST0170
      N=IT                                                              GUST0180
      TOL=1.0E-14                                                       GUST0190
      AA=2.0E+00/PI**2.0E+00                                            GUST0200
      AB=-62.E+00/(3.0E+00*PI**4.0E+00)                                 GUST0210
      AC=15116.0E+00/(15.0E+00*PI*6.0E+00)                              GUST0220
      AD=-12554474.0E+00/(105.0E+00*PI*8.0E+00)                         GUST0230
      P(1)=1.0E+00                                                      GUST0240
      EN=FLOAT(N)                                                       GUST0250
      NP1=N+1                                                           GUST0260
      U=1.0E+00-(2.0E+00/PI)**2.0E+00                                   GUST0270
      D=1.0E+00/SQRT((EN+0.5E+00)**2.E+00+U/4.0E+00)                    GUST0280
      DO 1 I=1,N                                                        GUST0290
      S=FLOAT(I)                                                        GUST0300
      A=4.0E+00*S-1.0E+00                                               GUST0310
      AE=AA/A                                                           GUST0320
      AF=AB/A**3.0E+00                                                  GUST0330
      AG=AC/A**5.0E+00                                                  GUST0340
      AH=AD/A**7.0E+00                                                  GUST0350
    1 Z(I)=PI*(A+AE+AF+AG+AH)/4.E+00                                    GUST0360
      DO 6 K=1,N                                                        GUST0370
      X=COS(Z(K)*D)                                                     GUST0380
    2 P(2)=X                                                            GUST0390
      DO 3 NN=3,NP1                                                     GUST0400
      ENN=FLOAT(NN-1)                                                   GUST0410
    3 P(NN)=((2.0E+00*ENN-1.E+00)*X*P(NN-1)-(ENN-1.E+00)*P(NN-2))/ENN   GUST0420
      PNP=EN*(P(N)-X*P(NP1))/(1.0E+00-X*X)                              GUST0430
      XI=X-P(NP1)/PNP                                                   GUST0440
      XD=ABS(XI-X)                                                      GUST0450
      XDD=XD-TOL                                                        GUST0460
      IF (XDD) 5,5,4                                                    GUST0470
    4 X=XI                                                              GUST0480
      GO TO 2                                                           GUST0490
    5 XKN(K)=X                                                          GUST0500
    6 AKN(K)=2.0E+00*(1.0E+00-X*X)/(EN*P(N)*EN*P(N))                    GUST0510
      DO 7 I=1,N                                                        GUST0520
      Z(I)=0.00                                                         GUST0530
    7 P(I)=0.00                                                         GUST0540
      RETURN                                                            GUST0550
      END                                                               GUST0560
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```
      SUBROUTINE ANGLE(PI,IANG)                                          ANGX0100
C     THIS ROUTINE IS TO BE USED TO REPLACE GUSET FOR THE PURPOSE        ANGX0110
C     OF USING AGAUSX TO DO PHASE FUNCTION CALCULATIONS AT -IT-          ANGX0120
C     ANGLES BETWEEN 0 AND 180 DEGREES, RATHER THAN AT THE G-L           ANGX0130
C     QUADRATURE ABSCISSA VALUES.                                        ANGX0140
      DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100),C(100)       ANGX0150
      COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,IT,ITT,NRADI         ANGX0160
      RADS=PI/180.E0                                                     ANGX0170
      DEL=180.E0/FLOAT(IT-1)                                             ANGX0180
      IF (IANG.EQ.2) GO TO 2                                             ANGX0190
      DO 1 I=1,IT                                                        ANGX0200
      H(I)=DEL*FLOAT(I-1)                                                ANGX0210
    1 C(I)=COS(H(I)*RADS)                                                ANGX0220
      RETURN                                                             ANGX0230
2     READ (5,100) (H(I),I=1,IT)                                         ANGX0240
      DO 3 I=1,IT                                                        ANGX0250
3     C(I)=COS(H(I)*RADS)                                                ANGX0260
      IANG=1                                                             ANGX0270
      RETURN                                                             ANGX0280
100   FORMAT (16F5.1)                                                    ANGX0290
      END                                                                ANGX0300
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      SUBROUTINE WATER(WVD,EMD,CAYD,TEMPD,DENSD)                        WATX0100
      REAL WAVE,LAMBDA(125),NSUBR(125),NSUBI(125),EMT,CAYT              WATX0110
      REAL TEMP(7),DENS(7)                                              WATX0120
C  THIS PROGRAM SEARCHES IRVINE AND POLLACK TABLE FOR REFRACTION        WATX0130
C  VS. WAVELENTH (ICARUS 8 PG 324 1968) AND THE DENSITY OF WATER        WATX0140
C  VS TEMPERATURE (HNDBK OF CHEM AND PHYS). IF THE INPUT VALUES         WATX0150
C  (TMCHUR AND WAVE) ARE NOT IN THE TABLES, A LINEAR INTERPOLATION      WATX0160
C  IS COMPUTED.  VALUES ARE ACCURATE TO THREE PLACES.                   WATX0170
      INTEGER P,POINT,H                                                 WATX0180
C            TABLES FOLLOW FOR 45 LINES                                 WATX0190
      DATA LAMBDA/0.20,0.25,0.30,0.35,0.40,0.45,0.50,0.55,0.60,0.65,    WATX0200
     1     0.70,0.75,0.76,0.80,0.806,0.85,0.90,0.95,0.97,1.00,1.05,1.06,WATX0210
     2     1.10,1.15,1.19,1.20,1.25,1.258,1.30,1.35,1.40,1.45,1.50,1.55,WATX0220
     3     1.60,1.65,1.66,1.70,1.75,1.80,1.85,1.90,1.94,1.95,2.00,2.05, WATX0230
     4     2.10,2.15,2.20,2.21,2.25,2.30,2.35,2.40,2.45,2.50,2.55,2.60, WATX0240
     5     2.625,2.65,2.70,2.75,2.80,2.90,2.95,3.00,3.10,3.20,3.30,3.40,WATX0250
     6     3.50,3.60,3.75,3.83,4.00,4.50,4.66,4.80,5.00,5.26,5.50,5.80,  WATX0260
     7     6.00,6.05,6.40,6.50,7.00,7.50,8.00,8.50,9.00,9.50,10.00,      WATX0270
     8     10.50,11.00,11.50,12.00,12.50,13.00,13.50,14.0,15.00,16.0,    WATX0280
     9     17.5,18.0,18.5,19.0,20.0,25.0,30.0,33.0,35.0,40.0,42.0,50.0,  WATX0290
     X     52.0,60.0,63.0,75.0,83.0,100.0,117.0,150.0,152.0,200.0/       WATX0300
      DATA NSUBR/1.424,1.377,1.359,1.349,1.343,1.339,1.336,1.334,1.332, WATX0310
     1     1.331,1.330,1.329,1.329,1.328,1.328,1.327,1.328,1.327,1.327, WATX0320
     2     1.326,1.325,1.325,1.324,1.3235,1.323,1.323,1.322,1.322,1.321,WATX0330
     3     1.320,1.320,1.319,1.318,1.317,1.316,1.316,1.315,1.315,1.314, WATX0340
     4     1.312,1.311,1.309,1.307,1.307,1.304,1.302,1.300,1.296,1.293, WATX0350
     5     1.292,1.290,1.286,1.282,1.276,1.270,1.246,1.213,1.180,1.160, WATX0360
     6     1.140,1.134,1.133,1.232,1.310,1.325,1.351,1.426,1.509,1.470, WATX0370
     7     1.449,1.423,1.402,1.372,1.358,1.349,1.341,1.338,1.336,1.331, WATX0380
     8     1.318,1.303,1.266,1.313,1.324,1.347,1.338,1.323,1.303,1.293, WATX0390
     9     1.286,1.269,1.245,1.214,1.185,1.151,1.145,1.160,1.190,1.220, WATX0400
     X     1.245,1.275,1.330,1.400,1.485,1.535,1.606,1.681,1.722,1.690, WATX0410
     1     1.652,1.636,1.615,1.577,1.567,1.590,1.609,1.670,1.696,1.760, WATX0420
     2     1.801,1.878,1.942,1.995,1.996,2.025/                         WATX0430
      DATA NSUBI/1.3E-07,6.0E-08,3.6E-08,8.0E-09,3.0E-09,7.0E-10,8.0E-10WATX0440
     1     ,1.5E-09,7.0E-09,1.3E-08,3.3E-08,1.49E-07,1.5E-07,1.34E-07   WATX0450
     2     ,1.2E-07,2.77E-07,4.80E-07,2.76E-06,3.55E-06,2.82E-06        WATX0460
     3     ,1.10E-06,1.07E-06,1.66E-06,7.32E-06,9.9E-06,9.74E-06        WATX0470
     4     ,8.85E-06,8.8E-06,11.17E-06,29.0E-06,14.48E-05,3.00E-04      WATX0480
     5     ,0.0002065,.0001184,0.0000789,6.7E-05                        WATX0490
     6     ,0.000066,0.0000697,0.0000891,0.0001146,0.0001399,0.001217,  WATX0500
     7     0.00176,0.001707,0.001082,0.0006689,0.0004345,0. 00325,      WATX0510
     8     0.000280,0.000272,0.000304,0.000421,0.000561,0.0 0802,       WATX0520
     9     0.001189,0.001651,0.001968,0.002048,0.002277,0.0 2763,       WATX0530
     X     0.005049,0.02401,0.09361,0.2435,0.2746,0.2586,0.1828,0.09422,WATX0540
     1     0.04333,0.01888,0.00930,0.00567,0.00355,0.00338, .00481,     WATX0550
     2     0.01472,0.01513,0.01647,0.01225,0.00959,0.01208, .03226,     WATX0560
     3     0.10208,0.11208,0.04339,0.04107,0.03443,0.03456, .03603,     WATX0570
     4     0.03768,0.04054,0.04377,0.05316,0.0690,0.1021,0.1530,0.2092, WATX0580
     5     0.2438,0.2918,0.3202,.3582,.4298,.4088,.3955,.3939,.3926,    WATX0590
     6     .3913,.3899,.37343,.33686,.3371,.3373,.38007,.40476,.51647,  WATX0600
     7     .55,.59446,.58,.56044,.5284,.5292,.5025,.49180,.5053,.51886/ WATX0610
      DATA TEMP/273.,278.,283.,288.,293.,298.,303./,DENS/               WATX0620
     1     0.999841,0.999965,0.999700,0.999099,0.998203,0.997044,       WATX0630
     2     0.995994/                                                    WATX0640
      EMT=0.0                                                           WATX0650
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      CAYT=0.0                                                          WATX0660
      POINT=0                                                           WATX0670
      H=0                                                               WATX0680
      WAVE=WVD                                                          WATX0690
      TMCHUR=TEMPD                                                      WATX0700
      IF (WAVE.LT.0.2.OR.WAVE.GT.200.0.OR.TMCHUR.LT.273.OR.             WATX0710
     1    TMCHUR.GT.303.0) GO TO 11                                      WATX0720
C     BINARY SEARCH                                                     WATX0730
      L=1                                                               WATX0740
      H=125                                                             WATX0750
    1 POINT=((L+H)/2)                                                   WATX0760
      TEST=ABS(LAMBDA(POINT)-WAVE)                                      WATX0770
      IF (TEST.LE.0.0001) GO TO 4                                       WATX0780
      IF (WAVE.GT.LAMBDA(POINT)) GO TO 2                                WATX0790
      H=POINT                                                           WATX0800
      GO TO 3                                                           WATX0810
    2 L=POINT+1                                                         WATX0820
    3 IF (L.NE.H) GO TO 1                                               WATX0830
      L=L-1                                                             WATX0840
C     INTERPOLATION ROUTINE                                             WATX0850
      EMT=NSUBR(L)+(NSUBR(L+1)-NSUBR(L))*((WAVE-LAMBDA(L))/(LAMBDA(L+1)-WATX0860
     1        LAMBDA(L)))                                               WATX0870
      CAYT=NSUBI(L)+(NSUBI(L+1)-NSUBI(L))*((WAVE-LAMBDA(L))/(LAMBDA(L+1)WATX0880
     1        -LAMBDA(L)))                                              WATX0890
      GO TO 5                                                           WATX0900
    4 CONTINUE                                                          WATX0910
      EMT=NSUBR(POINT)                                                  WATX0920
      CAYT=NSUBI(POINT)                                                 WATX0930
C   SEARCH TEMP VS DENS                                                 WATX0940
    5 IF (TMCHUR.LT.273.0.OR.TMCHUR.GT.303.0) GO TO 11                  WATX0950
      L=1                                                               WATX0960
      H=7                                                               WATX0970
    6 P=((L+H)/2)                                                       WATX0980
      TESTT=ABS(TEMP(P)-TMCHUR)                                         WATX0990
      IF (TESTT.LE.0.0001) GO TO 9                                      WATX1000
      IF (TMCHUR.GT.TEMP(P)) GO TO 7                                    WATX1010
      H=P                                                               WATX1020
      GO TO 8                                                           WATX1030
    7 L=P+1                                                             WATX1040
    8 IF (L.NE.H) GO TO 6                                               WATX1050
      L=L-1                                                             WATX1060
      RHODEN=DENS(L)+(DENS(L+1)-DENS(L))*(TMCHUR-TEMP(L))/(TEMP(L+1)-   WATX1070
     1        TEMP(L))                                                  WATX1080
      GO TO 10                                                          WATX1090
    9 RHODEN=DENS(P)                                                    WATX1100
   10 CONTINUE                                                          WATX1110
      EMD=EMT                                                           WATX1120
      CAYD=CAYT                                                         WATX1130
      DENSD=RHODEN                                                      WATX1140
      GO TO 13                                                          WATX1150
   11 WRITE (6,12) TMCHUR,WAVE                                          WATX1160
   12 FORMAT (10H TEMP. OF ,E12.6,14H OR WAVEL. OF ,E12.6,14H BEYOND RANWATX1170
     1        27H   OF DATA IN WATER ROUTINE/22H EXECUTION TERMINATED ) WATX1180
      STOP                                                              WATX1190
   13 RETURN                                                            WATX1200
      END                                                               WATX1210
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      SUBROUTINE AGXPRT(SCATT,KEXTT,KSCAT,KBAKT,CATTN,IANG,ITOT,NUNIT)  PRTX0100
      REAL KEXTT,KSCAT,KBAKT                                            PRTX0170
      DIMENSION F(513),R(513),C(100),PSUM(100),SCATT(100),SCAT(100)     PRTX0180
      DIMENSION PL(100,100),OL(100),RMS(100),PC(100),H(100),DR(8),RR(9) PRTX0190
      COMMON /BK2/PL,OL,RMS,PC,C,H,ALBDO,LLLL,NCRDS,IT,ITT,NRADI        PRTX0200
      COMMON /BK3/F,R,PSUM,SCAT,RR,DR,WAVE,EM,CAY,EMM,PI,IDSTP,         PRTX0210
     +       MQRTE,NKG,NHALV,NI                                         PRTX0220
      WRITE (6,3)                                                       PRTX0230
      WRITE (6,4) KEXTT                                                 PRTX0240
      WRITE (6,5) KSCAT                                                 PRTX0250
      WRITE (6,6) KBAKT                                                 PRTX0260
      WRITE (6,7) CATTN                                                 PRTX0270
      IF (IT.LT.2) GO TO 22                                             PRTX0280
      WRITE (6,8)                                                       PRTX0290
      IF (IANG.EQ.0) GO TO 17                                           PRTX0300
      WRITE (6,11)                                                      PRTX0310
      DO 16 J=1,IT,4                                                    PRTX0320
      K=J+3                                                             PRTX0330
      IF (K.GT.IT) K=IT                                                 PRTX0340
   16 WRITE (6,14) (H(I),PSUM(I),I=J,K)                                 PRTX0350
      GO TO 19                                                          PRTX0360
   17 WRITE (6,10)                                                      PRTX0370
      DO 18 J=1,IT,4                                                    PRTX0380
      K=J+3                                                             PRTX0390
      IF (K.GT.IT) K=IT                                                 PRTX0400
   18 WRITE (6,13) (C(I),PSUM(I),I=J,K)                                 PRTX0410
      WRITE (6,9)                                                       PRTX0420
C     THE FOLLOWING PREVENTS AN EXTRA SET OF OL'S FROM BEING WRITTEN     PRTX0430
C     OUT ON NUNIT.                                                     PRTX0440
      ITOT=5                                                            PRTX0450
      CALL GAUS(PSUM,NUNIT,ITOT)                                        PRTX0460
      GO TO 22                                                          PRTX0470
   19 WRITE (6,2)                                                       PRTX0480
      WRITE (6,12)                                                      PRTX0490
      DO 20 J=1,IT,4                                                    PRTX0500
      K=J+3                                                             PRTX0510
      IF (K.GT.IT) K=IT                                                 PRTX0520
   20 WRITE (6,14) (H(I),SCATT(I),I=J,K)                                PRTX0530
   22 RETURN                                                            PRTX0540
    2 FORMAT (1H0,/,1X,45X,20HSCATTERING FRACTIONS/)                    PRTX0550
    3 FORMAT (1H0/,1X,45H RESULTS AVERAGED OVER PARAMETER NWAVE FOLLOW/)PRTX0560
    4 FORMAT (/1X,20H EXTINCTION COEF. = ,5X,1PE12.5,9H (PER KM))       PRTX0570
    5 FORMAT (/1X,20H SCATTERING COEF. = ,5X,1PE12.5,9H (PER KM))       PRTX0580
    6 FORMAT (/1X,25H BACK-SCATTERING COEF. = ,1PE12.5,9H (PER KM))     PRTX0590
    7 FORMAT (/1X,21H ATTENUATION COEF. = ,4X,1PE12.5,13H SQ-METERS/MG) PRTX0600
    8 FORMAT (1H0,/,1X,50X,14HPHASE FUNCTION/)                          PRTX0610
    9 FORMAT (1H0/,1X,25X,1HL,20X,16HL-TH COEFFICIENT,23X,5HRMS   ,     PRTX0620
     +        9HDEVIATION/)                                            PRTX0630
   10 FORMAT (1H0,3X,4(5H   MU,8X,17HPHASE FUNCTION   )/)               PRTX0640
   11 FORMAT (1H0,18X,4(20H  ANGLE   PF-VALUE  )/)                      PRTX0650
   12 FORMAT (1H0,18X,4(20H  ANGLE     SCAT    )/)                     PRTX0660
   13 FORMAT (1H ,4(F13.9,E17.10))                                      PRTX0670
   14 FORMAT (1H ,18X,4(1X,F6.2,1X,E12.7))                              PRTX0680
      END                                                               PRTX0690
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      SUBROUTINE GPHASX(PSUM,PL,COEF,EMU,EMO,W,PA,GPFN,OM,PI,NUNIT,L,     GPHX0100
     +NCRDS)                                                              GPHX0110
C     THIS ROUTINE WILL COMPUTE THE GHG ANALYTIC PHASE FUNCTION WHEN      GPHX0120
C     IAPX .GT. ZERO.  SUBROUTINES GUSSTX AND PRINTX ARE ALSO NEEDED.     GPHX0130
      DIMENSION PSUM(100),PL(100,100),COEF(100),EMU(100),EMO(100),W(100)GPHX0140
     +,PA(100),GPFN(100),OM(100)                                          GPHX0150
      DO 1 I=1,L                                                          GPHX0160
      PL(I,I)=0.E0                                                        GPHX0170
      EMU(I)=0.E0                                                         GPHX0180
      EMO(I)=0.E0                                                         GPHX0190
      W(I)=0.E0                                                           GPHX0200
      PA(I)=0.E0                                                          GPHX0210
      GPFN(I)=0.E0                                                        GPHX0220
1     OM(I)=0.E0                                                          GPHX0230
C     ASYMMETRY FACTOR                                                    GPHX0240
      TRUEG=COEF(2)/(3.E0*COEF(1))                                        GPHX0250
C     CALCULATE GAUSS-LEGENDRE WEIGHTS AND ANGLES, ORDER L                GPHX0260
      CALL GUSSTX(EMO,EMU,PA,W,L,PI)                                      GPHX0270
C     CONSTRUCT ANGLES FROM COSINES                                       GPHX0280
      DO 2 I=1,L                                                          GPHX0290
2     EMO(I)=180.E0*ACOS(EMU(I))/PI                                       GPHX0300
C     CONSTRUCT LEGENDRE POLYNOMIALS                                      GPHX0310
      DO 15 J=1,L                                                         GPHX0320
      PL(1,J)=1.E0                                                        GPHX0330
15    PL(2,J)=EMU(J)                                                      GPHX0340
      DO 16 I=3,L                                                         GPHX0350
      EI=I-1                                                              GPHX0360
      DO 16 J=1,L                                                         GPHX0370
16    PL(I,J)=((2.E0*EI-1.E0)*EMU(J)*PL(I-1,J)-(EI-1.E0)*PL(I-2,J))/EI    GPHX0380
C     PHASE FUNCTION AT ZERO DEGREES                                      GPHX0390
      C=PSUM(1)/COEF(1)                                                   GPHX0400
      ITR=0                                                               GPHX0410
      DELL=0.1E0                                                          GPHX0420
      ONE=1.E0                                                            GPHX0430
      G=1.E0+DELL                                                         GPHX0440
      TOLER=1.E-04                                                        GPHX0450
      RHS=0.5E0*COEF(3)/COEF(1)                                           GPHX0460
4     ITR=ITR+1                                                           GPHX0470
      G=G-DELL                                                            GPHX0480
      FAC1=1.E0-G                                                         GPHX0490
      ELHS=G*(FAC1*FAC1*C-1.E0+1.5E0*G)                                   GPHX0500
      TEST=ELHS-RHS                                                       GPHX0510
      IF (ABS(TEST/RHS).LE.TOLER) GO TO 3                                 GPHX0520
C     THE FOLLOWING INSURES THAT G STARTS AT 1. AND GOES DOWNWARD         GPHX0530
      IF ((ITR.EQ.1).AND.(TEST.GT.0.E0)) ONE=-ONE                         GPHX0540
      TEST=ONE*TEST                                                       GPHX0550
      IF (G.LT.0.E0) GO TO 14                                             GPHX0560
      IF (TEST.LE.0.E0) GO TO 4                                           GPHX0570
      G=G+DELL                                                            GPHX0580
      DELL=DELL/PI                                                        GPHX0590
      IF (ITR.EQ.100) GO TO 3                                             GPHX0600
      GO TO 4                                                             GPHX0610
3     GSQ=G*G                                                             GPHX0620
      ALPHA=RHS/GSQ-0.5E0                                                 GPHX0630
      FAC1=1.E0-GSQ                                                       GPHX0640
      FAC2=1.E0+GSQ                                                       GPHX0650
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      TWOG=2.E0*G                                                       GPHX0660
      HALF=0.5E0*ALPHA                                                  GPHX0670
      FAC3=1.E0-HALF                                                    GPHX0680
      FAC4=(ALPHA-2.E0)*G                                               GPHX0690
C     GOEDECKE PART OF PHASE FUNCTION                                   GPHX0700
      DO 5 J=1,L                                                        GPHX0710
      DEN=FAC2-TWOG*EMU(J)                                              GPHX0720
      DENOM=SQRT(DEN)                                                   GPHX0730
      TEMP=(HALF*FAC1/DEN+FAC3)/DENOM                                   GPHX0740
      GPFN(J)=COEF(1)*TEMP                                              GPHX0750
C      PFN GOES NEG: USE HG FOR LATTER PART                             GPHX0760
      IF (TEMP.LT.0.E0) GO TO 6                                         GPHX0770
5     CONTINUE                                                          GPHX0780
C      GHG PFN NOT NEG: SKIP HG PART                                    GPHX0790
      GO TO 7                                                           GPHX0800
6     J1=J-1                                                            GPHX0810
      FAC4=EMU(J1)*FAC4                                                 GPHX0820
C     HG PFN                                                            GPHX0830
      DO 8 J=J1,L                                                       GPHX0840
      DEN=FAC2-TWOG*EMU(J)                                              GPHX0850
      DENOM= SQRT(DEN)                                                  GPHX0860
8     GPFN(J)=COEF(1)*(FAC2-ALPHA*GSQ+FAC4)/(DEN*DENOM)                 GPHX0870
7     CONTINUE                                                          GPHX0880
      OMO=0.E0                                                          GPHX0890
C     INTEGRATE GHG PFN FOR APPROXIMATE OMEGA ZERO                      GPHX0900
      DO 9 J=1,L                                                        GPHX0910
9     OMO=OMO+GPFN(J)*W(J)                                              GPHX0920
      OMO=0.5E0*OMO                                                     GPHX0930
C     RENORMALIZE                                                       GPHX0940
      DO 10 J=1,L                                                       GPHX0950
10    GPFN(J)=COEF(1)*GPFN(J)/OMO                                       GPHX0960
C     CONSTRUCT APPROXIMATE LEGENDRE COEFFICIENTS                       GPHX0970
      DO 11 I=1,L                                                       GPHX0980
      EN=FLOAT(I-1)                                                     GPHX0990
      FAC1=EN+0.5E0                                                     GPHX1000
      DO 11 J=1,L                                                       GPHX1010
11    OM(I)=OM(I)+FAC1*GPFN(J)*PL(I,J)*W(J)                             GPHX1020
      SUM=0.E0                                                          GPHX1030
      PHASE0=0.E0                                                       GPHX1040
      DO 12 I=1,L                                                       GPHX1050
C     ANALYTIC PFN AT ZERO DEGREES                                      GPHX1060
      PHASE0=PHASE0+OM(I)                                               GPHX1070
C     INTEGRATE ANALYTIC PFN OVER THETA                                 GPHX1080
12    SUM=SUM+GPFN(I)*W(I)                                              GPHX1090
C     NOW OVER PHI                                                      GPHX1100
      SUM=SUM*2.E0*PI                                                   GPHX1110
      ERR=ABS(SUM-4.E0*PI*COEF(1))/(4.E0*PI*COEF(1))*100.E0             GPHX1120
      CALL PRINTX (EMU,GPFN,OM,PHASE0,SUM,ERR,TRUEG,L,PSUM,NUNIT,NCRDS) GPHX1130
      RATIO1=(OM(1)-COEF(1))/COEF(1)*100.E0                             GPHX1140
      RATIO2=(OM(2)-COEF(2))/COEF(2)*100.E0                             GPHX1150
      RATIO3=(OM(3)-COEF(3))/COEF(3)*100.E0                             GPHX1160
      WRITE (6,100) RATIO1,RATIO2,RATIO3                                GPHX1170
100   FORMAT (1X,/,1X,10X,26HPERCENT ERRORS: OMEGA 0 = ,F8.3/,1X,26X,   GPHX1180
     +10HOMEGA 1 = ,F8.3/,1X,26X,10HOMEGA 2 = ,F8.3)                    GPHX1190
      RETURN                                                            GPHX1200
14    WRITE (6,101)                                                     GPHX1210
101   FORMAT (1X,44H THERE EXISTS NO MATCHING G - PRG TERMINATED)       GPHX1220
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      STOP                                                      GPHX1230
      END                                                       GPHX1240
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      SUBROUTINE GUSSTX(EMO,EMU,PA,W,L,PI)                              GUSX0100
C     THIS ROUTINE IS ESSENTIALLY THE SAME AS GUSET.                    GUSX0110
C     EMU IS COS ANGLE AND W ARE WEIGHTS, EMO,PA ARE TEMPORARY.         GUSX0120
      DIMENSION EMU(100),EMO(100),PA(100),W(100)                        GUSX0130
      TOL=1.0E-14                                                       GUSX0140
      N=L                                                               GUSX0150
      AA=2.0/PI**2                                                      GUSX0160
      AB=-62./(3.*PI**4)                                                GUSX0170
      AC=15116./(15.*PI**6)                                             GUSX0180
      AD=-12554474./(105.*PI**8)                                        GUSX0190
      PA(1)=1.00E+00                                                    GUSX0200
      EN=N                                                              GUSX0210
      NP1=N+1                                                           GUSX0220
      U=1.00E+00-(2.00E+00/PI)**2                                       GUSX0230
      D= 1.0E+00/SQRT((EN+0.5E+00)**2+U/4.0E+00)                        GUSX0240
      DO 1 I=1,N                                                        GUSX0250
      SM=I                                                              GUSX0260
      AZ=4.*SM-1.                                                       GUSX0270
      AE=AA/AZ                                                          GUSX0280
      AF=AB/AZ**3                                                       GUSX0290
      AG=AC/AZ**5                                                       GUSX0300
      AH=AD/AZ**7                                                       GUSX0310
    1 EMO(I)=0.25*PI*(AZ+AE+AF+AG+AH)                                   GUSX0320
      DO 6 K=I,N                                                        GUSX0330
      X=COS(EMO(K)*D)                                                   GUSX0340
    2 PA(2)=X                                                           GUSX0350
      DO 3 NNN=3,NP1                                                    GUSX0360
      ENN=NNN-1                                                         GUSX0370
    3 PA(NNN)=((2.0E+00*ENN-1.00E+00)*X*PA(NNN-1)-(ENN-1.0E+00)*        GUSX0380
     *PA(NNN-2))/ENN                                                    GUSX0390
      PNP=EN*(PA(N)-X*PA(NP1))/(1.0E+00-X*X)                            GUSX0400
      XI=X-PA(NP1)/PNP                                                  GUSX0410
      XD=ABS(XI-X)                                                      GUSX0420
      XDD=XD-TOL                                                        GUSX0430
      IF(XDD)5,5,4                                                      GUSX0440
    4 X=XI                                                              GUSX0450
      GO TO 2                                                           GUSX0460
    5 EMU(K)=X                                                          GUSX0470
    6 W(K)=2.00E+00*(1.00E+00-X*X)/(EN*PA(N)*EN*PA(N))                  GUSX0480
      RETURN                                                            GUSX0490
      END                                                               GUSX0500
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      SUBROUTINE PRINTX(EMU,PHFN,COEFS,PHASEO,SUM,ERROR,G,L,PSUM,NUNIT, PNTX0100
     +NCRDS)                                                           PNTX0110
      DIMENSION EMU(100),PHFN(100),COEFS(100),PSUM(100),IO(4)          PNTX0120
      WRITE (6,100) G                                                  PNTX0130
      WRITE (6,101) PSUM(1)                                            PNTX0140
      WRITE (6,102) PHASEO                                             PNTX0150
      WRITE (6,103)                                                    PNTX0160
      DUMSCT=0.E0                                                      PNTX0170
      DO 1 I=1,L                                                       PNTX0180
      IF ((NCRDS.EQ.2).OR.(NCRDS.EQ.3))                                PNTX0190
     +                    WRITE (NUNIT,111) DUMSCT,PHFN(I),EMU(I),I    PNTX0200
1     CONTINUE                                                         PNTX0210
      DO 4 I=1,L                                                       PNTX0220
      II=I-1                                                           PNTX0230
      IF ((NCRDS.EQ.1).OR.(NCRDS.EQ.3)) WRITE (NUNIT,110) COEFS(I),II  PNTX0240
4     CONTINUE                                                         PNTX0250
      DO 2 I=1,L,4                                                     PNTX0260
      K=I+3                                                            PNTX0270
      IF (K.GT.L) K=L                                                  PNTX0280
2     WRITE (6,104) (EMU(J),PHFN(J),J=I,K)                             PNTX0290
      WRITE (6,105) COEFS(1),SUM,ERROR                                 PNTX0300
      WRITE (6,106)                                                    PNTX0310
      WRITE (6,107)                                                    PNTX0320
      DO 3 I=1,L,4                                                     PNTX0330
      IO(1)=I                                                          PNTX0340
      IO(2)=I+1                                                        PNTX0350
      IO(3)=I+2                                                        PNTX0360
      IO(4)=I+3                                                        PNTX0370
      K=I+3                                                            PNTX0380
      IF (K.GT.L) K=L                                                  PNTX0390
3     WRITE (6,108) (IO(J-I+1),COEFS(J),J=I,K)                         PNTX0400
      RETURN                                                           PNTX0410
100   FORMAT (1H1,30X,38H     GHG PHASE FUNCTION FOR ASYMMETRY ,       PNTX0420
     +13HFACTOR (G) = ,F7.4,/)                                         PNTX0430
102   FORMAT(1X,38X,43H     GHG PHASE FUNCTION AT ZERO DEGREES IS      PNTX0440
     +,F9.4,/)                                                         PNTX0450
101   FORMAT(1X,38X,43HCOMPUTED PHASE FUNCTION AT ZERO DEGREES IS ,    PNTX0460
     +F9.4,/)                                                          PNTX0470
103   FORMAT (1X,50(1H-),12H GHG VALUES ,50(1H-)/,                     PNTX0480
     +        1X,2X,4(5H   MU,8X,17HPHASE FUNCTION   )/)               PNTX0490
104   FORMAT (1X,4(F13.9,E17.10))                                      PNTX0500
105   FORMAT(1X,/,1X,10X,14HTRUE OMEGAO = ,F7.4,3X,33HINTEGRATED GHG PHAPNTX0510
     +SE FUNCTION  = ,F8.4,2X,20HAND PERCENT ERROR = ,F8.4)            PNTX0520
106   FORMAT (1X,/,1X,44X,20H    GHG COEFFICIENTS,/)                   PNTX0530
107   FORMAT(1X,24X,4(6X,2HL ,5X,5HOMEGA),/)                           PNTX0540
108   FORMAT (28X,4(2X,I2,2X,E12.6))                                   PNTX0550
110   FORMAT (E25.14,1X,I5)                                            PNTX0560
111   FORMAT (3(E12.6,1X),I5)                                          PNTX0570
      END                                                              PNTX0580
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